THE LUNG

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AFFECTIONATELY DEDICATED
TO
MY WIFE

CONTENTS

PREFACE TO THE SECOND EDITION

No fundamental change has been made in the second edition of this book It is practically the same as the previous edition, but a few additions and changes have been made Several cuts have been replaced by better ones Additional illustrations will be found in chapters IV, VI, and IX Professor Larsell has restudied the nerves in the visceral pleura, and the results of his study have been incorporated in Chapter IX

The reception accorded the first edition, and the generous approval by the reviewers have been very gratifying to the author In general the reviewers have recognized that the author's desire, in publishing these contributions to the structure of the lung, is to have them serve as a stepping stone to help other workers to carry the work still further

The author does not claim to have said the final word on the structure of the lung Far from it There remains much to be done, no one realizes it more than he

During the interval between the two editions much time has been spent in further study of the epithelium lining the pulmonary alveoli No reason has been found to change the opinion expressed in the first edition that there is an epithelium lining the alveoli and that it is continuous Some workers think differently In time the solution of the problem will be worked out

Madison, Wisconsin

PREFACE

In the following chapters I have brought together many of the facts I have learned from forty seven years' study of lung structure There remain many problems to be solved I trust that this contribution will serve as a stepping stone to help others toward their solutions

In the spring of 1887, I spent some time working in the laboratory of the College of Physicians and Surgeons, then located on 23rd Street and 4th Avenue, New York Francis Delafield at that time Professor of Medicine, was advancing the thesis that free communications existed between the air spaces in the lungs In this he was supported by J West Roosevelt, who showed that by picking apart complete wax corrosions of the lung under a dissecting microscope small more or less spheroidal bodies could be isolated, and that they had two or more facets, which represented points of communication with similar bodies I was so impressed by this that I made it the subject of my work at Clark University Worcester, Massachusetts

At first everything seemed to confirm the statements of Delafield and of Roosevelt I made numerous corrosions in wax and in Wood's metal I found the spheroidal bodies of Roosevelt, and they had the facets which he described Later, I made a reconstruction from one of my series in which the arteries and veins had been injected with different colored masses, and acquired very complete positive and negative models On dissecting these models I discovered that the spheroidal body of Roosevelt was not a sacculus alveolaris but a distinct air space, to which I eventually gave the name *atrium* Each sacculus was very irregular in shape and had only a *single* facet, while the atrium more or less spheroidal, had *several* facets This I have found true in all lungs from which I have made reconstructions I have especially illustrated an atrium in Figures 30 and 31

From 1892 to 1924 I was actively engaged in instructional work at the University of Wisconsin In such spare time as was available which included a year at Leipzig and, later, a year at Johns Hopkins, I continued my study of the structure of the lung Since the close of my instructional work I have made numerous reconstructions Some have been used in illustrating this brochure, but others belong on the border line between the normal and pathological anatomy of the lung

I hesitated before deciding to use the BNA nomenclature. Eventually I adopted it, because, as explained in the text, it is universally understood; English equivalents of the terms are also given.

Since 1919, in public addresses and published papers I have advocated the use of the term *hilum* in place of hilus. I did this because the word hilus is not found in Latin lexicons, also because Hyrtl in his *Onomatologia Anatomica* had shown that hilus was incorrect. Today the term hilus is gradually being replaced by *hilum*.

It is my pleasant duty to acknowledge the kindness of the Director of Wistar Institute in permitting me to reproduce text or illustrations from the various publications of the Institute: *The Journal of Morphology, The Anatomical Record, The American Journal of Anatomy,* and *The Journal of Comparative Neurology*. The editors of the following journals have also granted permission to use material published: *The American Review of Tuberculosis, Journal of Experimental Medicine, Radiology, Contributions to Embryology*; and the publishers of the *Reference Handbook of Medical Sciences*. Finally I must acknowledge with gratitude my indebtedness to the group of unknown friends who, under the leadership of Dr. Lawrason Brown, of Saranac Lake, have made this publication possible.

Madison, Wisconsin

SOURCE OF THE ILLUSTRATIONS

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THE LUNG

Chapter I

THE LUNGS

The lungs are two irregular conical shaped organs which occupy, one on either side the thoracic cavity They are separated from each other by a median partition the mediastinum, in which are situated the heart enclosed within the pericardium, the thoracic aorta and the arteries arising from its arch the thoracic duct, and the great veins entering the heart They are indirectly connected with each other by the trachea and the two main bronchi into which it divides Below the hilum the two folds of the pleura, which enclose the lung leave it and form by their union the ligamentum pulmonale by which the lung is attached to the pericardium and esophagus

Color At birth and for the first three weeks of life the lungs are

The adult lungs vary in color depending on the amount of blood which they contain and the amount of pigmentation present If there be but little blood present they have a yellowish gray color but when they contain a considerable quantity of blood they are

phere When extreme pigmentation is present (be it from particles of carbon or dust) it may give a light bluish black color to the surfaces of the lungs on which appear lines or patches of more intense pigmentation The external surfaces of the lungs, as a rule, show a greater amount of pigmentation than either the mediastinal surfaces or the bases of the lungs the surfaces within the fissures show the least pigmentation

Weight *It is difficult to determine the weight of the lungs owing* to the variable quantity of fluid present Krause gives 1,300 grams as the weight in the male and 1 023 grams in the female, with a moderate amount of blood present Under the same conditions I have found the average weight somewhat less 1 058 grams in the male and 924 grams in the female The average weight of the right lung in the male was found to be 568 75 grams in the female, 500 grams The average weight of the left lung in the male was 486 88

grams, in the female, 424 grams From these figures it is seen that the right lung materially exceeds the left in weight.

Spitzka found the weight of the lungs still lower in the case of six criminals executed by electricity In age, they varied from twenty-three to forty-one years The right lung averaged 281 grams, the left lung, 253 grams, giving a total weight of 534 grams for both lungs This is practically half the average weight which I found Spitzka attributes the low weights in his cases to the [illegible] of death which, by [illegible] and other phenom[illegible] lungs, so that we are enabled to ascertain the actual weight of lung tissue only, not, as in ordinary death of a variable amount of blood and serum as well "

Specific Gravity Before respiration has taken place, the specific gravity of the lungs is greater than that of water, they sink, therefore, when placed in it The same is true when only a few inspirations have taken place and the lungs have collapsed with the death of the individual Waters gives 1,062 and Wilmart 1,068 as the specific gravity before the establishment of respiration After the establishment of respiration the lungs become filled with air and their specific gravity may be as low as 0 342 (Dwight)

Dimensions Owing to variations in size and form of the thorax and to variations in distention, any measurements of the lungs are of little value Krause gives 271 millimeters as the length of the right lung in males and 216 millimeters in females, of the left lung, 298 millimeters in males and 230 millimeters in females Measured transversely at the base, the right lung is 135 millimeters, the left lung 129 millimeters in diameter in males, in females the right lung measures 122 millimeters, the left lung 108 millimeters

The right lung is shorter and broader than the left lung This is due to the liver's causing the arch of the diaphragm to rise to a higher level on the right side than on the left, and to the inclination of the heart to the left side

Capacity. In a well developed male of from thirty to thirty-five years of age, at the end of a full inspiration the lungs contain about 5,000 c c of air, in a female, somewhat less After death and collapse of the lungs have taken place, the lungs contain about 1,500 c c of air According to Hutchinson, the vital capacity, which is the greatest amount of air that can be expelled after a full inspiration, is 3,700 c c Rosenthal gives 3,200 c c for males and 2,500 c c for females

Schafer, as the result of a series of experiments, found that with a respiration of thirteen per minute the amount of air exchanged per minute was 5,850 c c , giving 450 c c as the amount of tidal air

Form When the lungs are hardened *in situ* they are, as stated above irregularly conical in shape and there can be distinguished on each an apex, a base three surfaces, and two margins

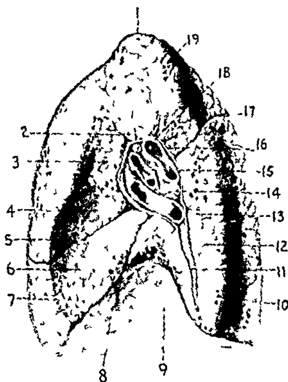


Fig 1 —Right Lung from the Medial Side 1 Apex pulmonis 2 facies mediastinalis 3 groove of the vena cava superior 4 lobus superior 5 impressio cardiaca, 6 lobus medius 7 margo anterior 8 margo inferior

Apex The *apex pulmonis* (Fig 1) is rounded and occupies the cupula pleurae It is not situated over the center of the basis pulmonis but mesial and somewhat posterior to it Below the apex

pulmonis runs a groove the sulcus subclavius occupied by the arteria subclavia (Fig 2)

Base The *basis pulmonis* is broad and concave the concavity corresponding to the curve of the liver from which it is separated

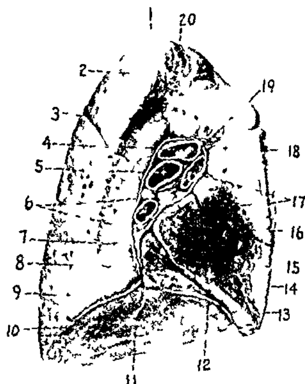


Fig 2—Left Lung from the Medial Side 1 Apex pulmonis 2 facies costalis 3 incisura interlobaris 4 ramus sinister of the arteria pulmonalis 5 bronchus

19 hilum pulmonis with cut edge of the pleura 20 sulcus subclavius (After Spalteholz)

by the *diaphragma* The arch of the *lobus hepatis dexter* extends to a higher level than that of the *lobus hepatis sinister*, consequently the concavity of the basis pulmonis of the right lung is deeper than that of the left lung (Figs 1 2)

Surfaces The *facies costalis* (Figs 3 4) is the most extensive of the three surfaces and is deeper posteriorly than anteriorly It is

which slightly rounded ridges appear that correspond to the inter costal spaces These intercostal ridges often show, especially in early life a greater amount of pigmentation than the costal grooves

The *facies mediastinalis* (Figs 1 2) is in contact with the *pleura mediastinalis* and the pericardium It is nearly vertical in direction and presents a deep concavity the *impressio cardiaca* which is larger and deeper on the left lung than on the right because of the oblique position which the heart occupies and its projecting further beyond the midline on the left side than on the right side This surface possesses near its posterior border above and behind the impressio cardiaca a triangular depression the *hilum pulmonis* in which the bronchi the blood vessels and nerves are situated as they enter and leave the lung and in which lymph nodes (*lymphoglandulae pulmonales*) are not infrequently found (Figs 1 2) Collectively these structures are called the root of the lung (*radix*

the hilum pulmonis to the pleura mediastinalis and forms the *ligamentum pulmonale* (Figs 1, 2) Situated behind the hilum pulmonis of the right lung and arching slightly above it is a groove for the *vena azygos* (Fig 1) In some instances a vertical groove can be recognized below that for the vena azygos and behind the ligamentum pulmonale for the esophagus In front of the hilum is a wide shallow groove which runs upward with a lateral curve for the *vena cava superior* and the *vena anonyma dextra* (Fig 1) On the left lung above and behind the hilum pulmonis and the ligamentum pulmonale is a broad deep groove produced by the *arcus aortae* and the *aorta thoracalis* (Fig 2) Running upward from the

pulmonis and has been described under that heading The encroachment of the heart gives the facies diaphragmatica of each lung a crescentic outline that of the left lung being the more typical on account of the oblique position of the heart

Radix Pulmonis The *radix pulmonis* is situated slightly above the center of the facies mediastinalis and nearer its posterior than its anterior border The arrangement of the bronchi and vessels

entering and leaving the lung differs on the two sides On the right lung (Fig 1) the main bronchus enters near the middle of the hilum, and its first branch near the upper border of the hilum As a rule, however, in dissecting the lung the bronchus is divided obliquely before it branches and then it appears as an irregular oval situated in the upper and posterior quadrant of the hilum In front and somewhat below the bronchus is the *ramus dexter arteria pulmonalis*, while below the bronchus and artery are the *venae pulmonales dextrae* On the left lung (Fig 2) the bronchus enters the hilum behind and slightly over its center, the *ramus sinister arteria pulmonalis* is situated above the bronchus, while the *venae pulmonales* are situated in front of and below the bronchus This variation in the arrangement of the structures forming the *radix pulmonis* causes the hilum of the right lung to have an ovoid outline while that of the left lung is triangular in outline

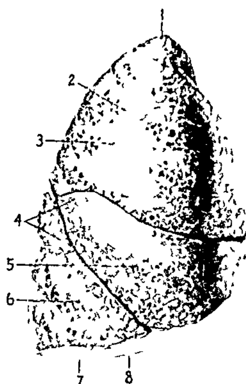


FIG 3 —Right Lung Anterolateral Aspect 1 Apex pulmonis, 2 facies costalis 3, lobus superior 4 incisurae interlobares, 5 lobus medius, 6 lobus inferior 7, margo inferior, 8 facies diaphragmatica (After Spalteholz)

Margins The *margo anterior* is thin, sharp and somewhat irregular Above, the margo anterior of each lung projects into the *sinus costomediastinalis*, below, that of the left lung presents a deep concavity, the *incisura cardiaca* where it curves around the heart (Fig 4) This prolongation of the lung below the heart toward the midline is called the *lingula pulmonis*

The *margo inferior* (Figs 1, 2) along the junction of the facies

matica it is thicker and more rounded The thick rounded dorsal portion of the lung at the junction of the facies costalis and the facies mediastinalis is sometimes described as a *margo posterior*

Fissures The lungs are divided into lobes by deep fissures (*incisurae interlobares*) On the left lung the incisura interlobaris passes obliquely from behind and above forward and downward to the basis pulmonis (Figs 3 4) A similar incisura interlobaris is present on the right lung from which a second incisura more horizontal and shorter passes across the anterior surface so that there can be recognized on the right lung two incisurae interlobares By means of these incisurae three lobes are marked off on the right lung a *lobus superior* a *lobus medius* and a *lobus inferior* on the left lung only two lobes are present a *lobus superior* and a *lobus inferior*

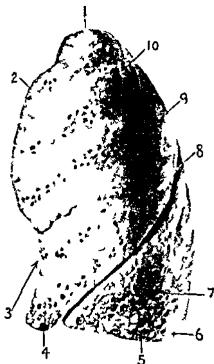


Fig 4 —Left Lung Anterolateral Aspect 1 Apex pulmonis 2 margo anterior 3 incisura cardiaca 4 lingula pulmonis 5 margo inferior 6 basis pulmonis 7 lobus inferior 8 incisura interlobaris 9 lobus superior 10 facies costalis (After Spalteholz)

Lobes The left lung is divided by the incisura interlobaris into a *lobus superior* and a *lobus inferior* The lobus superior is situated above the incisura interlobaris It is conical in form with an oblique base which corresponds to the cardiaca it is prolonged toward the midline forming the *lingula pulmonis* The lobus inferior comprises the remainder of the lung Nearly the whole of the facies diaphragmatica (basis pulmonis) and a large part of the facies costalis belong to this lobe (Fig 4)

The right lung is divided by two incisurae interlobares into three lobes. One of the incisurae occupies practically the same position as that of the left lung except that it is more vertical in direction and does not terminate as near the midline. It separates the lobus inferior from the lobus medius and the lobus superior. The second incisura separates the lobus superior from the lobus medius. It leaves the main incisura near the dorsal part of the lung, passes horizontally forward to the level of the fourth costal cartilage, where it cuts the margo anterior, and then passes across the facies mediastinalis to terminate at the hilum pulmonis.

The lobus medius is wedge shaped and is the smallest of the three lobes. Interposed as it is between the lobus superior and the lobus inferior it gives to the lobus superior the form of a truncated cone, the apex of which is formed by the apex pulmonis. In like manner the lobus inferior has the form of a truncated cone when viewed from in front and laterally, the base being formed by the facies diaphragmatica (Fig. 3).

Blood Vessels. The blood vessels of the lung consist of two sets which originate from different sources and perform functions of a different character. One set, derived from the arteria pulmonalis, gives origin to the respiratory or functional circulation; the other set, derived from the arteria bronchialis, furnishes the nutritive vessels of the lung.

The *arteria pulmonalis* arises from the ventriculus dexter of the heart, passes obliquely along the left side of the aorta ascendens and divides under the arcus aortae into a ramus dexter and a ramus sinister. The *ramus dexter* passes behind the aorta ascendens and the vena cava superior and beneath the arcus aortae to gain a position in front of the bronchus dexter at the hilum pulmonis. The *ramus sinister* runs in front of the bronchus sinister and the aorta thoracalis and enters the hilum pulmonis above the bronchus sinister. Within the lung the arteria pulmonalis follows the bronchi in all of their subdivisions and is situated behind and slightly lateral to the bronchi. The branches of the arteria pulmonalis

are usually four in number, two for each lung. In some instances the vein coming from the lobus medius of the right lung empties into the atrium sinistrum independently; in other instances the two veins arising from the left lung unite and form a common trunk before entering it. The finer arrangement of the pulmonary blood vessels will be considered in Chapter V.

The *arteriae bronchiales* vary in number and origin; the right ar

teria bronchialis arises either directly from the aorta thoracalis or from the first or third arteria intercostalis, the left arteriae bronchiales, two in number, arise from the anterior wall of the aorta thoracalis at the level of the fifth vertebra thoracalis. The blood which the arteriae bronchiales convey to the lungs is largely returned by the venae pulmonales. True venae bronchiales are found only at the hilum pulmonis; they empty into the vena azygos or the vena hemiazygos. The bronchial artery and its distribution is described in detail in Chapter I.

Lymphatics. Grossly the lymphatics of the lungs can be divided into a superficial and a deep set. The former is situated in the pleura pulmonalis, the latter accompanies the rami bronchiales, the arteria pulmonalis and the venae pulmonales. The two sets communicate in the pleura and at the hilum pulmonis. A more extended description will be found in Chapter VI.

Nerves. The lungs receive their nerve supply from the nervi vagi and the rami pulmonales of the pars thoracalis systematis sympathici. The nervus vagus forms on the posterior surface of the radix pulmonis a plexus (*plexus pulmonalis posterior*); from this plexus branches pass to the anterior surface of the radix pulmonis where they form a second plexus (*plexus pulmonalis anterior*). The plexus pulmonalis posterior is joined by branches from the second, third and fourth ganglia thoracalia. The plexus pulmonalis anterior is joined by a few fibers from the plexus cardiacus profundus of the same side. The anterior plexus supplies the constituents of the radix pulmonis, while the posterior plexus sends branches which contain fibers from both the nervus vagus and sympathicus into the substance of the lung. The finer distribution of the nerves will be described in Chapter VIII.

Chapter II

THE TRACHEA AND BRONCHI

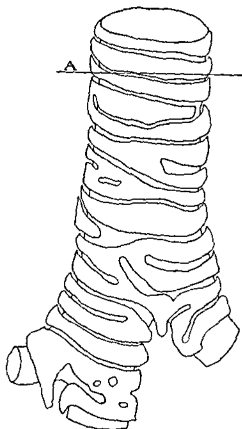


Fig 5 —Outline of a reconstruction of the lower portion of the trachea of a week old child Only a part of the uppermost cartilage enters into the reconstruction The line drawn across the reconstruction indicates the plane of section Note the angle at the bifurcation the greater diameter of the right bronchus and that the carina is at the left of the midline ×6

The trachea consists of a framework of cartilaginous crescents sixteen to twenty in number, which are connected with each other by a dense layer of connective tissue, the *ligamentum annularia*, and lined on the interior with a *tunica mucosa* Posteriorly, where the cartilages are wanting the trachea is flattened and, situated between the external fibrous tunic and the mucosa bundles of smooth muscle connect the cartilages with each other

Cartilages The cartilages present marked irregularities They may split and fusions with adjoining cartilages are not unusual In the reconstruction illustrated (Fig 5) the first of the cartilages is incomplete and must therefore, be left out of the account, the two following cartilages are regular in their formation the next five are either fused or bifurcated and have one or more irregular openings evidently due to incomplete development for they give passage to neither blood vessels nerves nor gland ducts The carinal cartilage is interesting being formed by the fusion of tracheal and left bronchial cartilages (Fig 6) both elements present bifurcations and irregularities of outline

The *carina tracheae* is a prominent ridge running anteroposteriorly across the bottom of the trachea between the origin of the two bronchi Heller and v Schrotter studied the relation of the cartilages to the carina in 125 tracheae As the result of their investigations tl
membranous
In case cartilage
into tracheal or bronchial ' according as the cartilage belonged

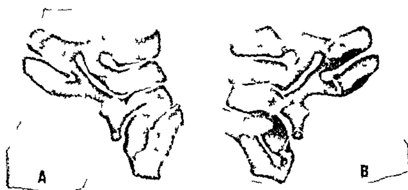


Fig 6 —Reconstruction of the carinal cartilage shown in outline in figure 5 A anterior view B posterior view Note the extension of fusion of tracheal and bronchial elements This belongs to what is known as the tracheo-bronchial left type of carinal cartilage X6

to a tracheal or a bronchial crescent When the cartilage was derived from a bronchial crescent it might be either bronchial right or bronchial left or when as in some cases both bronchial cartilages entered into the carina double bronchial Occasionally a fused tracheal and bronchial crescent entered the carina in such cases the carina was described as tracheo bronchial and like the simple bronchial it could be either right or left (Fig 7)

As the result of their study of the 125 tracheae they found the carina cartilaginous in 56%, membranous in 33%, partly membranous in 11% In 27% where cartilage was present it was tracheal 15%, bronchial right 3%, bronchial left 3 5%, double bronchial

The first bronchial cartilage on the right side of the reconstruction (Fig 5) consists of two elements which fuse as they arch around the medial side of the bronchus The next cartilage is a typical crescent Immediately below this cartilage the eparterial bronchus is given off and the cartilage placed at this point has a

complicated structure part of it belonging to the eparterial bronchus and part to the main stem bronchus The portion belonging to the eparterial bronchus has a prolongation which is associated with a small bronchus arising from the eparterial bronchus which is not shown in the outline

On the left side the bronchial cartilages fuse with the tracheal cartilages to form a tracheo bronchial left carinal cartilage

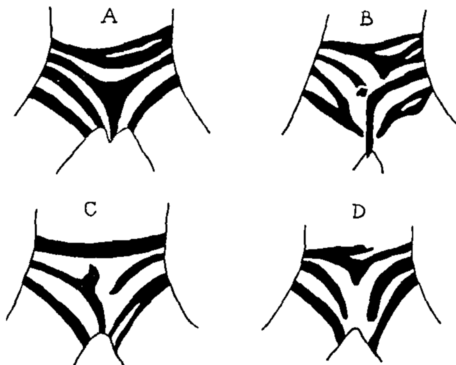


Fig 7 —Types of the *carina tracheae* View from behind The cartilages are represented by solid black bands A tracheal B bronchial right C bronchial left D membraneous (After Heller and von Schrötter)

(Fig 5) which consists of two irregularly fused tracheal elements and three bronchial elements The two succeeding cartilages also fuse to form a single element but are not indicated in the drawing of the reconstruction

Muscle Cuvier apparently was the first to note that in some animals the bundles of smooth muscle were inserted on the outer surface of the cartilages while in other animals they were inserted on the inner surface In the carnivora the attachment is external while in monotremes and insectivora the attachment is internal In animals that live on a vegetable diet the attachment is usually

internal, but in the rabbit it is external. In man, who lives on a mixed diet, the attachment is internal. I have failed to find any assignable cause for this variation. Guieysse, who paid special attention to this varied attachment, also failed to find any explanation.

If a freshly removed trachea, with the bronchi attached, be so divided that the carina is cut as near its center as possible and the

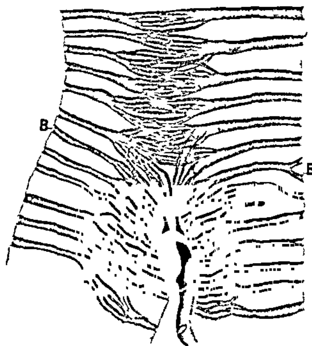


Fig 8 —The arrangement of the trachealis muscle at the carina of a new born child Internal attachment of the muscle B first bronchial cartilage The posterior spur triangle is crossed by two bands of muscle ×6

posterior half placed in Ranvier's alcohol for thirty-six to forty-eight hours, at the end of that time the mucosa can be removed
from its anterior
and glands from
placed in fifty per
has been added to
it should be removed to pure glycerin and spread out flat, using a compressorium if necessary.

In a trachea thus prepared it will be found that the muscle is made up of branching and anastomosing bands which extend between the cartilages (Fig 8) Whatever the position of the muscle be it external or internal it is not inserted into the extreme tip of the cartilage but into the perichondrium some distance from the extremity of the cartilage

Both Verson and Frankenhauser have described scattered bands of smooth muscle ending in the connective tissue between the cartilages I have failed to find this type of ending The musculature of the adult human trachea differs from that of the new born child in that the bands of muscle connected with a given cartilage maintain to a greater extent their independence than in the new born child where they form a more complex network

Longitudinal bands of smooth muscle have been described by Reis eisen Piersol v Ebner and others, it seems to me that the statement by Cramer and by Luschka that they are exceptional covers the case *Possibly some of those who have described a longitudinal layer of muscle have mistaken* as did Thomas Willis the longitudinal layer of elastic fibers for smooth muscle though v *Ebner places them outside of the circular layer of muscle and con*sequently they could not have been mistaken for the elastic layer which is situated internal to the muscular layer

Arrangement of the Muscle at the Carina *If a trachea be divided* 25 or 30 mm above its bifurcation on looking into the cut end there can be seen running in an anteroposterior direction across the bottom of the trachea between the two bronchi and somewhat to the left of the midline a semilunar ridge the *carina tracheae* The margins of the carina diverge as they reach the anterior wall of the trachea and form the lateral boundary of what Heller and v Schrotter term the anterior spur triangle ' Posteriorly there is also formed a smaller posterior spur triangle ' The former of these does not concern us but the latter must be considered in connection with the arrangement of the bands of muscle at *this point*

Converging bands of muscle extend between the ends of the last tracheal cartilage and in the case of the bands on the left side the last two or even three *tracheal cartilages and* the posterior portion of the carina These converging bands of muscle and the transverse bands connecting the ends of the last tracheal cartilage *form the boundary of a triangular area* which varies in extent and corresponds to the posterior spur triangle of Heller and v Schrotter The higher origin of the left bands of muscle is a constant factor These converging bands are situated internal to the tracheal bands whenever they cross them (Fig 8)

Elastic Fibers A closely interwoven layer of elastic fibers situ

ed between the muscular layer and the mucosa, runs lengthwise ong the trachea Zuckerkandl has correlated the longitudinal ds of the trachea (Fig 9) with bundles of elastic fibers The stic fibers appear in the form of bundles because of the folds, e folds are formed by the contraction of the trachealis muscle d the inherent elasticity of the cartilages, and not by bundles of stic fibers

Glands The tracheal glands belong to the tubulo-acinar type ney are situated in the submucosa and are more abundant in the terior wall of the trachea than in the lateral wall

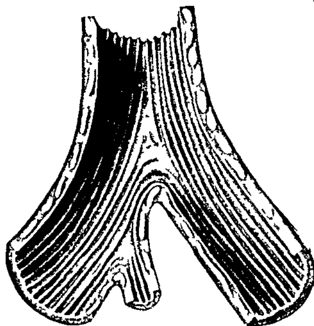


Fig 9 — Longitudinal folds in the trachea formed by the contraction of the trachealis muscle and the elasticity of the cartilages

In the posterior membranous wall they are situated not only in e submucosa but also within and behind the muscular layer, so at their ducts pass through the muscular layer in order to reach e surface of the mucosa Not infrequently the ducts open on the rface of the mucosa by a funnel-shaped enlargement In longiudinal sections of the trachea the glands are seen to be grouped clusters between the cartilages

Tracheal and Bronchial Epithelium By some authors for example F E Schulze the epithelium is described as consisting of a single layer of ciliated columnar cells interspe...
cells Where...
who con
of the ep
true that ... epithelium often appears to consist of a single layer but a close stu...
ferent ...

t
c ... four types can be recog



Fig 10 —Section of the epithelium lining a bronchus 3 mm in diameter ×500

nized (1) basal cells (2) Ersatzzellen or intermediate cells (3) ciliated cells and (4) goblet cells Of these four types the ciliated and the goblet cells exceed the others in number (Fig 10)

Basal Cells The basal cells form the deepest row of cells and they are situated just above the basement membrane Their nuclei are sometimes round sometimes elongated and parallel to the basement membrane on which the cells rest Dividing nuclei are not often seen Drasch has described basal cells as dividing in such a manner that the resulting cells lie one above the other on the other hand cells are sometimes seen dividing in the opposite direction

Intermediate Cells The intermediate cells form the second layer and have various shapes due to the pressure exerted by the adjoining cells They are in general spindle shaped and often

extend from the basement membrane to the surface of the epithelium When this is the case the outer end usually tapers to a point or it may end in a rounded extremity

Ciliated Cells The ciliated cells of the trachea and the larger bronchi belong to the columnar type, in the bronchioles they belong to the cuboidal type The outer free ends of the ciliated cells possess a thickened, cuticular border which bears the cilia Chambers and Renyi have shown that it is only at this cuticular border that ciliated cells have a continuity 'The apparent continuity between contiguous cells of this type does not seem to be an organic one in the same sense as that which exists in squamous stratified epithelium Injury of one cell, they find is not transmitted to adjoining cells The lower or attached end of the ciliated cell is much smaller than the free end it may be rounded, or it may be divided into a number of fine prolongations The ciliated cells extend through the entire thickness of the epithelial layer and their lower ends always reach the basement membrane At the place where the ducts coming from the mucous glands enter the trachea or bronchi the ciliated cells line the trumpet shaped opening and extend some distance into the duct

As stated by Kolliker ciliated epithelium extends beyond the point where goblet cells disappear it does not however form a complete layer, for interspersed with the ciliated cells there are numerous non ciliated cells Moreover the type of the cilia bearing cells changes from a columnar to a cuboidal epithelium, which is the predominating type of epithelium in bronchioli between 0 3 mm and 0 4 mm in diameter

Goblet Cells The goblet or chalice cells like the ciliated cells, extend through the entire thickness of the epithelial layer As their name implies they often have an outline which may be compared to that of a goblet but the pressure exerted by the adjoining cells frequently modifies their outline Their lower or attached end is applied to the basement membrane This may be expanded into a foot it may end in a pointed prolongation or like the ciliated cells in a number of fine prolongations Their free end varies in outline sometimes it is widely open then again it may be contracted into what may be compared to the neck of a bottle Their nuclei are usually situated on the same plane as those of the adjoining ciliated cells As a rule goblet cells are more abundant in the larger bronchi than in the trachea In sections cut parallel to the surface of the epithelium or in surface views of the epithelium the portion of the goblet cells can be recognized by their clear more or less round openings in the midst of the finely granular ends of the ciliated cell While goblet cells are found abundantly in the

larger bronchi, they diminish in number as the bronchi diminish in diameter, and finally disappear in bronchioli of 0.4 mm. in diameter.

Throughout the tracheal and bronchial epithelium scattered lymphocytes are found, but I have not found, in the normal lung, those collections described by some authors.

Regeneration. The basal cells give origin to the restitution or intermediate cells ("Ersatzzellen" of Kölliker, "Keilzellen" of Drasch), and the intermediate cells give origin on the one hand to

[illegible]

are not infrequently seen with a row of cilia around the circumference of their opening. This seems to indicate that they represent a mucous degeneration of the ciliated cells, a view that is taken by *Waller and Björkman, F. Merkel, Knauff, and Kölliker.*

The occurrence of mitotic figures in the tracheobronchial epithelium is rarely noted. Bockendahl has found them scattered through the tracheal epithelium, but he considers regeneration of the epithelium, under normal conditions, to be very inactive, a conclusion previously reached by Henle.

As previously stated, occasionally basal cells with two nuclei are found, and in one instance a ciliated cell with two nuclei has been seen.

Stratified Squamous Epithelium. The earliest accounts of stratified squamous epithelium in the human trachea with which I am acquainted are found in papers by Griffini and by Baraban. Baraban found areas of squamous epithelium in the trachea of an executed criminal. It has not been my fortune to find this type of epithelium in the human trachea, but I have found it in the human bronchi. Baraban thinks that the transition of ciliated epithelium into stratified squamous epithelium is due to a low grade of irritation which leads to the loss of the cilia and to the appearance of mucus in the cells.

As was the case with Griffini, all the instances in which I have found stratified squamous epithelium in the human bronchi have been from tuberculous lungs (Fig. 11). As suggested by Baraban, it was probably the constant coughing that played the chief rôle in the change from ciliated to stratified squamous epithelium.

Lymphatics. According to Teichmann, the lymphatics of the trachea consist of two layers which are connected with each other by anastomoses: an outer, situated in the tunica mucosa, and an inner overlying layer.

In that portion of the trachea containing cartilaginous crescents

the principal trunks run parallel to the cartilages On the other hand, in the membranous portion their direction is changed they bend around the end of the cartilage crescents and run more in the long axis of the trachea Those branches of the inner layer which

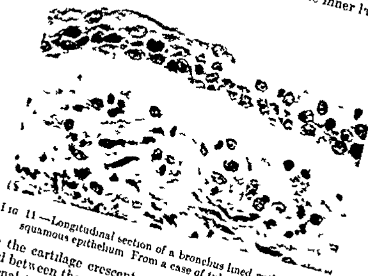


Fig 11 —Longitudinal section of a bronchus lined with stratified squamous epithelium From a case of tuberculosis ×500

run on the cartilage crescents are thinner than those which are situated between the cartilages

External to the vessels of the inner layer and between them originate trunks provided with valves (They are best seen in longitudinal sections of the trachea) These in general lie between the cartilages and run to the right and left until they have reached the membranous portion of the trachea From here the vessels take different directions according to the situation of the nodes into which they empty

Chapter III

INTRAPULMONARY BRONCHI AND BRONCHIOLI

The trachea divides into the right and left bronchus The level at which this takes place varies, according to Mehnert, with the age of the individual In the new-born child it most frequently takes place at the level of the third thoracic vertebra, but it may be as low as the fourth In the adult it usually divides about the level of the intervertebral disk between the fourth and fifth thoracic vertebrae, it may, however, divide as low as the fifth or sixth thoracic vertebra

The earlier anatomists described the right bronchus as having a more horizontal direction than the left bronchus Engel, followed by Pansch, was the earliest I have found to maintain the opposite view namely, that the right bronchus followed closely the general direction of the trachea, while the left bronchus diverged at a greater angle

The angle at which the two bronchi are given off varies, according to Kobler and v Hovorka, with the age of the individual In 16 new born children the angle at which the right bronchus was given off varied from 10° to 35°, for the left bronchus the angle varied from 30° to 65° In an adult male the right bronchus was given off at an angle of 20°, the left bronchus at an angle of 40° In an adult female the right bronchus was given off at an angle of 19°, the left bronchus at an angle of 51° The angle of divergence averaged 70°

Aeby demonstrated that there is a main bronchus, gradually diminishing in size which extends through each lung These main bronchi are direct continuations of the two bronchi into which the trachea divides From each main bronchus lateral branches, rami bronchiales are given off in a monopodial manner, these lateral branches were named by Aeby dorsal and ventral bronchi The dorsal bronchi are usually shorter and more slender than the ventral bronchi

According to Aeby, the arteria pulmonalis, as it passes to each lung crosses the main bronchus near its upper part and, running along its lateral side, gradually comes to lie dorsal to the bronchus All lateral bronchi which arise from the main bronchus, below the place where the arteria pulmonalis crosses, were called by Aeby hyparterial bronchi On the right side in man a single, rather large bronchus arises from the main bronchus, above the place where

the pulmonary artery crosses, and was called by Aeby the eparterial bronchus

Occasionally in man the eparterial bronchus arises directly from the trachea this point of origin is constant in sheep and in the ox Below the point where the arteria pulmonalis crosses the main bronchus, the arrangement of the lateral bronchi is the same on each side This peculiarity of the bronchi leads to the formation of three lobes for the right lung but of only two for the left Aeby reasons that as the eparterial bronchus is not present on the left side the lobe to which it is distributed is absent, and that the upper lobe of the left lung and the middle lobe of the right lung are homologous

This conception of Aeby which he evolved from his studies of the comparative anatomy of the lungs received confirmation from His, who studied the development of the lungs in human embryos of various ages His showed that from the first there was an unsymmetrical arrangement of the lung buds there being three on the right side but only two on the left He agreed with Aeby that the mode of branching for the main bronchus was monopodial but disagreed as to the lateral bronchi which he claimed were dichotomous in their mode of branching

Ewart in his work on the bronchi and blood vessels of the human lungs differs from Aeby He believes in dichotomy not the even dichotomy of the older authors but uneven dichotomy He says The further dissection is carried within the lung the less rarely does even dichotomy occur In another place he says The products of a dichotomy which had been carried through with mathematical precision would have fitted ill within the pleural boundaries Nay even the more elastic principle of monopodial branching requires in its working to be allowed some latitude All so-called principles, or laws are overruled by a higher law the law of adaptation

Narath denies that the arteria pulmonalis influences the development of the bronchial tree He claims that the eparterial bronchus on the right side is homologous with the dorsal branch arising from the first ventral bronchus on the left side The eparterial bronchus according to Narath is therefore a dorsal lateral branch of the first ventral bronchus which has migrated up the main bronchus In a later communication he studied the problem from the embryological side and found confirmation of his previously expressed opinion

As the result of a series of comparative anatomy studies Huntington reaches the conclusion that the right and left lungs agree

morphologically in the type of their bronchial distribution This leads to the following propositions

Right side	Left side
Upper middle lobe =	Upper lobe
Lower cardiac lobe =	Lower lobe

Huntington agrees with Narath that migration and not the arteria pulmonalis *is the active principle in modifying the archi tecture of*
apical bro
tington as

In a number of contributions d Hardwiller opposes the theory of dichotomy supporting Aeby *in this respect but strongly op* poses him in the manner in which the bronchi arise from the main stem The lungs are at first symmetrical and have on each side an eparterial bronchus Deviations from this type are to be referred to the result of atrophy The eparterial bronchus is not a lateral branch of a hyparterial bronchus as described by Narath but is a special bronchus

Birch Hirschfeld has investigated the bronchial tree of adults and agrees with Narath that the upper part of the left lobe corresponds to that part of the right lung which is supplied by the eparterial bronchus From a pathological standpoint Birch Hirsch feld thinks that only such branches should be designated apical as are exclusively distributed to the upper portion of each lung

A recent study by Justesen of the division of the bronchi leads him to the conclusion that the mode of division is a modified dichotomy in which one branch becomes much more highly de veloped than the other This type of division is designated by him sympodial a name applied by botanists to a similar mode of branching in plants

Flint has made an extended study of the development of the bronchial tree and he finds that the growth of the main series of bronchi is monopodial in character subsequent division of the branches may be either monopodial or dichotomous the type depending on the space in which the bronchi have to divide

In my own studies of the mode of division in the adult lung I have found that the mode of division for the main series is mono podial but that the mode of division for the smaller bronchi is a mixed dichotomy and monopody

Cartilages The shape position and relationship of the intra pulmonary cartilages form an interesting study Some time ago I

and bronchi with their cartilages in the guinea pig and the trachea certain of the bronchi and their cartilages in man

While the tracheal and pulmonary cartilages in man are usually described as hyaline Cutore and other investigators have described the bronchial cartilages as containing elastic fibers thus making the intrapulmonary cartilages fibro-elastic cartilages I have myself found this type in a few instances but further study is necessary to establish this as the predominant type in the human lung If it is not the predominant type where is it more frequently found in the bronchi or in the cartilaginous bronchioli?

There are numerous problems which were brought out by the reconstructions that need further study What relation do the cartilages bear to the bronchial musculature? Is the mu cle ever attached to the cartilages? What are the mechanics of the support the cartilages give to the bronchi especially where branches are given off and what is the medium of the support? What influence does age exert on the cartilages? Not one of the e questions has received a satisfactory answer



Fi 12—Outline of the ection along the line X in figure 5 Note circular outline of the section The numbers 2 3 4 indicate the cartilages through which the plane of the section passes ×6

As the bronchi are followed into the lung the cartilages have at first much the same form as in the trachea but gradually the membranous interval between the ends of the more or less crescent shaped cartilages changes from a posterior to a mesial position along the main stem bronchus

The u ual statement that with the entrance of the main bronchus into the lung and its breaking up into branches the cartilages no longer appear as crescents but become irregular shaped plates which are scattered along the length of the bronchi is only partly correct If followed through serial sections these plates are found to be parts of distinct cartilages just as sections through the trachea show that the segments found in an individual section belong to distinct cartilages (Fig 12)

The shape of the cartilages at the place where bronchi divide is of interest Horner was the first to call attention to their peculiar shape he says "At the orifice of each branch of the bronchia there is a semi lunar cartilage forming rather more than one half of its circumference and having its concave edge upwards The whole arrangement resembles somewhat the pasteboard of an e ared bonnet and is evidently to keep the orifice open Horner

does not give an illustration of these peculiarly shaped cartilages, but King gave, in his short account of the bronchial cartilages several small and unsatisfactory drawings of this form of cartilage, he also said that cartilages at the place where bronchi divide did



FIG 13 —A typical saddle-shaped cartilage in the lung of the guinea pig situated at the first division of the main stem bronchus in the left lobus inferior A shows the cartilage *in situ* when seen from the dorsal side B when seen from the ventral side C shows the cartilage alone ×22

not always have this characteristic saddle shape but were subject to a considerable number of varieties' I have found this form of cartilage not only in man (Fig 13) but also in the guinea pig (Fig

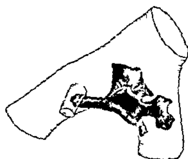


FIG 14 —Dorsal view of a small typical saddle-shaped cartilage shown *in situ* Its relation to the two principal bronchi is clearly shown also the prolongation by which it comes into relation with a third bronchus The bronchi are shown as though transparent ×15



FIG 15 —A small bronchus from the lung of a guinea pig surrounded by a ring shaped cartilage which is quite irregular in its formation ×15

14) I have also found another type of cartilage circular in shape, which surrounds a bronchus at the point where it leaves its main stem bronchus In roentgenograms of the lung small circular densities are often seen which have been interpreted as being due to a bronchus which opens either directly toward or away from the

observer. It may be possible that the density is caused by one of these ring shaped cartilages, especially when it has the form of Figure 15.

Eventually a point is reached where cartilages *are* found in the form of irregular plates. This is the first step in their final disappearance. The point where they disappear from the bronchi is

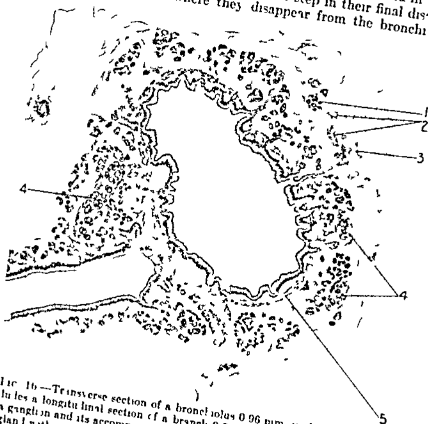


Fig. 16.—Transverse section of a bronchiolus 0.96 mm. in diameter which includes a longitudinal section of a branch 0.34 mm. in diameter. 1, section of a ganglion and its accompanying nerve; 2, sections of the bronchial artery; 3, gland with its duct opening on the inner surface of the bronchiolus; 4, sections of cartilages; 5, smooth muscle in the wall of the bronchiolus. ×35.

variously stated. Frankenhäuser says in bronchi 0.4 mm. in diameter, Kolliker in bronchi 0.85 mm., Spalteholz, Henle, Krause and others say in bronchi 1 mm. in diameter. From numerous measurements I have made it appears to me that the point varies in different individuals and even in the same lung. My own average gives between 0.6 mm. and 0.7 mm. Whatever the diameter of the bronchus may be where cartilage disappears, the last bit, often in

the form of a slender rod rather than a plate is found where a bronchiolus divides

Figure 16 is a transverse section of a bronchiolus 0 96 mm in diameter cut in such a manner that a longitudinal section of a branch 0 24 mm

pa o a saddle shaped cartilage while the remaining cartilages are plates Both ciliated epithelium and glands are present in the branch of b t

E

wise

and the mucosa Where ducts from the glands situated in the sub mucosa open into their lumen the fibers arch around them (Fig 17) The arrangement of the elastic fibers is the same where a branch is given off from either a bronchus or a bronchiolus (Fig 40)

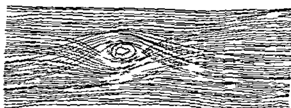


Fig 17—Arrangement of the elast c f bers in a medium-s zed bronch olus at the place where the duct of a gland opens nto its lumen Semi d agram mat c

Muscle The earliest description of the musculature of the bron chi was given by Reisseisen He described it as being attached to the bronchial cartilages and spreading out so as to fill the spaces between the cartilages The muscle did not disappear at the point

a scalpel Reisseisen inferred from this that it extends to the ulti mate end of the bronchial tube Because he gave the primary description of the bronchial musculature later investigators have frequently called it the *Muscle of Reisseisen*

Following Reisseisen there is a long list of investigators who have made mention of the muscle and have given various descriptions of its arrangement From this list the descriptions given by the following authors have been selected as the best representatives of of the diverse opinions



Fig. 18.—Muscle bands in a bronchiole from the lung of a guinea pig. ×190

E Schultz describes the muscle as forming a completely closed layer Frankenhauser describes the muscle as a *Ringmuslelschicht* which forms in the human lung a muscular *tube which only occa* sional breaks in its continuity F E Schulze describes the muscle as consisting of smooth muscle fibers that pursue a circular course but he adds that toward the end of the terminal branch the layer gradually grows thinner and finally breaks up into individual ring bands which are separated from each other by more or less broad fissures These bands often consist of only a single layer of muscu *lar cells but are at the same time interwoven with delicate elastic* fibers

Toldt gives a more detailed description of the muscular layer He describes the muscle as forming a completely closed layer in the bronchi of the cat but the walls of the bronchi in man also have smooth muscle bundles in their entire circumference They are situated just beneath the tunica propria of the mucosa and form a connected but not a complete layer Their arrangement is lattice like (gitterformig) as can be best demonstrated in bronchi which have been cut open and spread out flat The muscle is arranged in *flat bundles which have in general a nearly transverse course and* unite to form a network Between these bundles there are spaces bounded by acute angles which are situated transverse to the long axis of the bronchi When the bronchi are cut transversely the muscle layer appears here and there to be interrupted and the smooth muscle bundles are cut not in a true longitudinal direc tion but more or less obliquely In the smallest interlobular bronchi *the muscle bundles are thin and consist of only a few cells and are* much further apart however they still surround the entire cir cumference of the bronchial tube

Kölliker says that while the general direction of the muscle bundles is transverse to the course of the bronchi they are so con nected that they form a network and nowhere do they form a closed layer as in the circular muscle layer of the intestine

Sappey *describes the muscle as being continuous and compares* it to the circular layer of muscle in the intestinal wall Dubreuil and Lamarque studied the musculature of the bronchi in the human lung and that of various domestic animals They give an illustration of the network of smooth muscle in an alveolar canal from the lung of an ox The muscle is described as a plexiform sphincter and according to their illustration the rather coarse *mesh of the network is elongated parallel to the long axis of the* ductulus alveolaris They support the statement made by Rind fleisch that muscle is present in the walls of the sacculi alveolares and alveoli

None of the above descriptions defines the type of the network

which the smooth muscle forms in the walls of the bronchi and bronchioli.

Having exhausted all attempts to find a technical term, I asked the assistance of President Max Mason, now of the California Institute of Technology, at that time (1920) Professor of Mathematical Physics at the University of Wisconsin. Very kindly he spent some hours of an afternoon going over my camera lucida drawings and the reconstruction model. He defined the network as a geodesic network. In a personal communication President Mason gives the following amplification:



FIG. 19.—Smooth muscle bands in the wall of a bronchiolus from the human lung. ×1[illegible]0.

A geodesic line on any surface is one of shortest distance (like arcs of

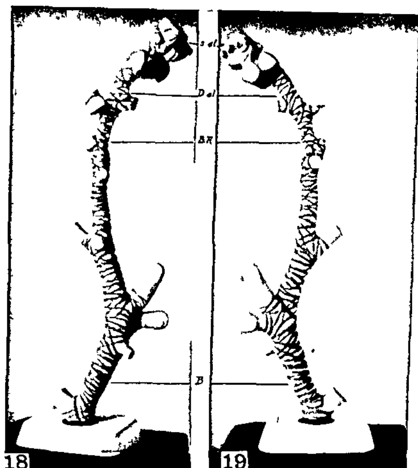


Fig 20 Fig 21

Fig 20 —Reconstruction showing the distribution of bands of smooth muscle along a bronchiolus and its subdivisions B , bronchiolus B R , bronchiolus respiratorius D Al ductulus alveolaris S Al sacculus alveolaris ×125 and reduced to 8

Fig 21 —Same reconstruction as figure 20 viewed from the opposite side See legend accompanying Figure 20

to withstand or produce pressures within the space enclosed by the surface, without a tendency to slip along the surface

For the study of muscle, use has been made of the lungs of the guinea pig cat, dog, rabbit, and man Figure 18 shows a section

from the lung of a guinea pig in which a cartilaginous bronchiolus 0 165 mm in diameter, is cut in such a plane that the muscle bands are divided somewhat obliquely, while in one of its branches, 0 125 mm in diameter only a portion of the upper segment of the bronchiolus is included in the section and this shows the bands of muscle arching over the wall of the bronchiolus

Fig 22—Diagrammatic section through Figure 20 Diameter measurements given in millimeters

The bands have an average thickness of 0 03 mm and they vary from 0 01 mm to 0 0265 mm in width The bronchiolus is contracted and this accounts for the close approximation of the bands A careful examination of the photomicrograph will however show the branching and anastomosing of the muscle bands

The lungs of the guinea pig contain proportionally a larger

amount of smooth muscle than those of any other animal I have studied It is the presence of this large amount of muscle in the bronchial tree and in the pleura that makes the lung of the guinea pig so difficult to distend

Figure 19 is a photomicrograph of a section of a non cartilaginous bronchiolus 0 65 mm in diameter from the human lung The plane of the section is such that the muscle bands are seen extending across the lower wall of the bronchiolus These bands are not as closely applied to one another as those in Figure 18 because the bronchiolus is extended and not contracted this permits the branching and anastomosing of the bands of muscle to be more clearly seen The bands vary from 0 02 mm to 0 03 mm in thickness and from 0 008 mm to 0 05 mm in width

In the lower portion of the figure the muscle bands are obscured by the extensive pigmentation It was on account of the large amount of pigmentation present in such human lungs as were available that the study was transferred to the dog s lung Numerous comparative studies have shown that no difference in the arrangement of the muscle in the two lungs could be discovered

Figures 20 and 21 show two views of a reconstruction from a dog s lung of the musculature of a non cartilaginous bronchiolus 0 565 mm in diameter its branches and its termination in a primary lobule of which only a single sacculus alveolaris is shown completely reconstructed All of the muscle bands were drawn by means of the camera lucida and placed on the model in as near their original position as possible By this method the width of the muscle bands their thickness their relation to each other their relation to the places where branches were given off from the bronchiolus and the distance to which muscle extended in the lung were ascertained



Fig 23 —Transverse section of a bronchiolus 1 mm in diameter ×500

As was the case with the bronchiolus illustrated in Figure 19 this bronchiolus is extended it is in the condition of full inspiration The angle at which the muscle bands diverge from each other shows a marked

contrast to those in Figure 18, and it also shows the advantage of studying the lung in the condition of full inspiration. The tendency of the muscle bands to have more or less of a triangular arrangement at the place where branches are given off is easily made out

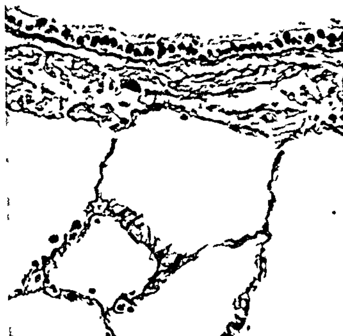


Fig. 21.—From a section of a bronchiolus 0.35 mm. in diameter. The type of the ciliated epithelium has changed from columnar to cuboidal. ×500.

In individual sections which have been cut in such a plane as to include the alveoli of an air tube but not the air tube itself, it is not improbable that the presence of muscle has led to the statement that muscle is present in the walls of the air spaces. The same may be true of alveoli belonging to sacculi alveolares which abut against a bronchiolus when they are cut in such a plane that only the muscle of the bronchiolus is included in the section. This has probably led to the statement that muscle bands penetrate to the bottom of the alveoli. Keeping in mind the fact that the "in-

amount of smooth muscle than those of any other animal I have studied It is the presence of this large amount of muscle in the bronchial tree and in the pleura that makes the lung of the guinea pig so difficult to distend

Figure 19 is a photomicrograph of a section of a non-cartilaginous bronchiolus 0 65 mm in diameter, from the human lung The plane of the section is such that the muscle bands are seen extending across the lower wall of the bronchiolus These bands are not as closely applied to one another as those in Figure 18, because the bronchiolus is extended and not contracted, this permits the branching and anastomosing of the bands of muscle to be more clearly seen The bands vary from 0 02 mm to 0 03 mm in thickness and from 0 008 mm to 0 05 mm in width

In the lower portion of the figure the muscle bands are obscured by the extensive pigmentation It was on account of the large amount of pigmentation present in such human lungs as were available that the study was transferred to the dog's lung Numerous comparative studies have shown that no difference in the arrangement of the muscle in the two lungs could be discovered

Figures 20 and 21 show two views of a reconstruction, from a dog s lung of the musculature of a non-cartilaginous bronchiolus, 0 565 mm in diameter its branches and its termination in a primary lobule of which only a single sacculus alveolaris is shown completely reconstructed All of the muscle bands were drawn by means of the camera lucida and placed on the model in as near their original position as possible By this method the width of the muscle bands, their thickness, their relation to each other, their relation to the places where branches were given off from the bronchiolus, and the distance to which muscle extended in the lung were ascertained



FIG 23 — Transverse section of a bronchiolus 1 mm in diameter ×500

As was the case with the bronchiolus illustrated in Figure 19, this bronchiolus is extended, it is in the condition of full inspiration The angle at which the muscle bands diverge from each other shows a marked

contrast to those in Figure 18, and it also shows the advantage of studying the lung in the condition of full inspiration. The tendency of the muscle bands to have more or less of a triangular arrangement at the place where branches are given off is easily made out in both Figures 20 and 21. This arrangement is quite characteristic and has probably a direct relationship to the arrangement of the elastic fibers at this point (see Fig. 40).

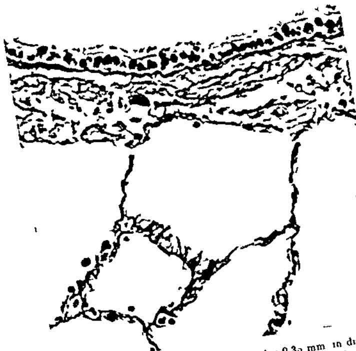


FIG. 24.—From a section of a bronchiolus 0.35 mm. in diameter. The type of the ciliated epithelium has changed from columnar to cuboidal. ×500.

In individual sections which have been cut in such a plane as to include the alveoli of an air tube but not the air tube itself, it is not improbable that the presence of muscle has led to the statement that muscle is present in the walls of the air spaces. The same may be true of alveoli belonging to sacculi alveolares which abut against a bronchiolus when they are cut in such a plane that only the muscle of the bronchiolus is included in the section. This has probably led to the statement that muscle bands penetrate to the bottom of the alveoli. Keeping in mind the fact that the 'in

fundibulum" of the old ... lus alveolaris, the ... made by Rindfleis... fibers of the smallest bronchioles send into the orifice of the in...



Fig 25 —Longitudinal section of a bronchiolus 0 35 mm in diameter A few ciliated cells of the cuboidal type can be seen on the right of the figure followed *to the left* they give place to a non ciliated cuboidal epithelium ×500



Fig 27 —From a longitudinal section of a bronchiolus respiratorius which shows a small portion of the wall of the bronchiolus between the openings leading into *two alveoli* The nuclei of three cuboidal cells can be seen and behind the epithelium the elongated nucleus of a smooth muscle cell From a bronchiolus respiratorius 0 25 mm in diameter ×500



Fig 26 —Transverse section of a bronchiolus respiratorius 0 35 mm in diameter Only a few alveoli were present along its walls ×500

fundibula some partial prolongations which penetrate to the bottom of them " If, however, serial sections be made use of (and they should be used in studying the structure of the lung), the proper relation of the muscle will be at once recognized

At the distal end of the ductulus alveolaris the muscle forms a sphincter about the openings leading into the atria (Fig 20) Distal to the sphincters about the openings leading into the atria, no

muscle is found As stated when describing the muscle about the alveoli opening out of the bronchioli respiratorii and ductuli alveolares, the muscle bands which form these sphincters belong to the musculature of the bronchial tree and not to the atria

Figure 22 is a diagrammatic outline of a median section through the reconstruction shown in Figure 20, and gives the diameter, in millimeters, of its various divisions At the lower end of the bronchiolus, where it is 0 565 mm in diameter, the muscle bands are 0 022 mm in thickness, in the ductulus alveolaris, which measures 0 192 mm in diameter, the muscle bands are 0 012 mm in thickness While the bronchiolus has diminished about 65 per cent in diameter, the muscle has diminished only about 43 per cent in thickness These results follow closely those obtained by Grancher, who found that in bronchi 10 mm in diameter the muscle was 0 2 mm in thickness, while in bronchioli 1 mm in diameter the muscle was 0 1 mm in thickness In other words, the muscle bands were five times as strong in a bronchiolus 1 mm in diameter as in a bronchus 10 mm in diameter

Epithelium of the Bronchioli The transition which the epithelium undergoes as the subdivisions of the bronchial tree approach their termination and alveoli appear along their walls, forms an interesting study In bronchioli of 1 mm in diameter the epithelial layer diminishes in thickness (Fig 23) Although there can still be recognized the various types of cells described in the trachea and bronchi, the ciliated cells far outnumber the other forms Only here and there can a goblet cell be distinguished, in many of the basal cells the nucleus is oval, with its long diameter parallel to the basement membrane As was the case in the larger bronchi, an occasional lymphocyte can be seen between the epithelial cells

Previous to the appearance of alveoli along the walls of the bronchioli the character of the epithelium changes The ciliated cells are now



Fig 23 —On the right side of the section the transition of the cuboidal epithelium of a bronchiolus respiratorius into the flattened epithelium lining a ductulus alveolaris can be followed while on the left side of the section a ductulus alveolaris is given off at a slightly higher level than on the right side consequently the few epithelial cells present are of the cuboidal type ×500

of the cuboidal instead of the columnar type (Fig 24) The goblet cells have disappeared but an occasional basal cell is seen The basement membrane when cut transversely, is reduced to a thin line In a longitudinal section of a bronchiolus which is dividing into bronchioli respiratorii a still further transformation of the epithelium can be followed The cilia bearing cells gradually disappear and are replaced by non ciliated cuboidal epithelium (Fig 25) which can be best seen in transverse sections of bronchioli respiratorii which have but few alveoli along their walls (Fig 26)

The non ciliated cuboidal epithelium persists throughout the bronchioli respiratorii In longitudinal sections of the bronchiolus it is seen on those small lengths of its wall which are found between the openings of the alveoli into its lumen (Fig 27)

In a longitudinal section through the wall of a [illegible] respiratorius at the place where [illegible] a still further modificatio[illegible] cuboidal cells which line th[illegible] olus respiratorius gradually become flattened (Fig 28) and eventually are transformed into the simple squamous epithelium (respiratory epithelium) which lines the walls of the pulmonary alveoli

Basement Membrane The basement membrane of the trachea and bronchi when any attempt has been made to describe it has been described as a clear homogeneous structureless membrane as derived from the subepithelial elastic layer or as made up of elongated cells placed end to end

The work of Mall on the reticulum gave a new conception of basement membranes and their composition He showed that in the case of the kidney and of the testis the cells rested on a delicate network of reticulum Flint in his study of the submaxillary and other glands found that the basement membrane in each instance was made up of reticulum thus confirming the work of Mall

The introduction of Bielschowsky's method of staining the fibrils of reticulum has simplified the digestion method of Mall for demonstrating these fibrils and throughout the entire framework of the lung it has been found that it is reticulum that forms the basement membranes on which the various types of cells rest

In the case of the trachea where the basement membrane is especially thick a few collagenous fibers can in some sections be demonstrated but within the lung the basement membrane of all the subdivisions of the bronchial tree is made up wholly of reticulum (Fig 24)

CHAPTER IV

THE AIR SPACES

Because it is a nomenclature extensively used and understood by all I have used the BNA nomenclature No attempt has been made to name the subdivisions of the bronchial tree previous to the appearance of alveoli along the walls of the bronchioli We have therefore the following

BNA	English equivalent
Bronchioli	Bronchioli
Bronchioli respiratorii	Respiratory bronchioles
Ductuli alveolares	Alveolar ducts Alveolar passages
Atria	Atria
Sacculi alveolares	Air sacs
Alveoli pulmonum	Air cells

If the main bronchus or one of its branches be followed toward its distal extremity a point is finally reached where cartilages are no longer present in the bronchial walls and the bronchi assume a tubular character with their walls largely made up of bands of smooth muscle These tubular bronchi have on transverse section a more or less circular outline and are called *bronchioli*

Eventually the tubular character of the bronchiolus changes and there are found small projections in increasing number on all sides of the bronchiolus These projections(alveoli) were recognized by Thomas Willis Moleschott and other early investigators

Schulze was the first to give a name to this division of the bronchial tree He called the entire portion of the bronchus which had alveoli projecting from its walls and was situated between a tubular bronchiolus and what was then known as an infundibulum an *alveolargang* (alveolar passage) Later Kolliker subdivided this lengthy division into a proximal portion which he called the *bronchiolus respiratorius* and a distal portion for which he retained the name originally given by Schulze to the entire passage *alveolargang* (now known as the *ductulus alveolaris*) basing his subdivision on th[illegible]

[illegible] general[illegible] to distinguish between an alveolus be

longing to a bronchiolus respiratorius or to a ductulus alveolaris and one belonging to an atrium or to a sacculus alveolaris The former is an alveolus which communicates with the lumen of an air tube and because of the arrangement of the muscle bands, has a greater or less amount of muscle in the knob, inverted T, or head of a cane-shaped wall, which forms the boundary of its opening into the air tube *The muscle belongs to the air tube and not to the alveolus*

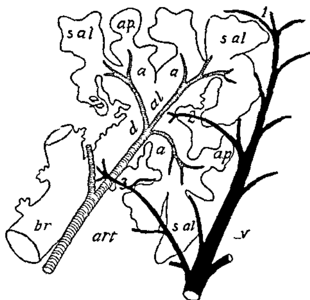


FIG 29—Schematic longitudinal section of a primary lobule of the lung showing the relation of the blood vessels to the air spaces b r bronchiolus respiratorius d al ductulus alveolaris a a a atria s al s al sacculi alveolares a p a p alveoli pulmonum art arteria pulmonalis with its branches to the atria and the sacculi v vena pulmonalis with branches from the pleura (1) from the ductulus alveolaris (2) and from the forking of the bronchiolus respiratorius (3) (After Miller 1900)

As far as the termination of the ductulus alveolaris, there is a general agreement among investigators but they disagree in regard to the structure of the lung distal to the ductulus alveolaris The fact that the pulmonary artery, which follows the subdivision of the bronchial tree can serve as a guide in following the finer divisions of the lung seems to have escaped the attention it deserves

In the chapter devoted to the blood vessels it will be found that,

as soon as the pulmonary artery has reached the distal extremity of the ductulus alveolaris, it divides into branches which correspond to subdivisions arising from the ductulus alveolaris that are quite distinct, in structure and form, from the ductulus, and that these branches of " [illegible]
correspond to still [illegible]

Returning now [illegible]
from the distal end of the ductulus alveolaris, there are from three to six more or less spherical cavities, the *atria* Each atrium communicates, on the one hand, with the ductulus alveolaris, on the other hand, with a variable number of larger and more irregular-shaped cavities, the *sacculi alveolares*, projecting from the walls of each sacculus and atrium there are a number of smaller spaces, the *alveoli pulmonum*

We now have the following nomenclature for the last divisions of the bronchial tree *bronchiolus* (by some called the "terminal bronchiole '), *bronchiolus respiratorius, ductulus alveolaris, atrium, sacculus alveolaris, alveolus pulmonum* The ensemble of ductulus alveolaris, atria sacculi alveolares, and alveoli, together with their accompanying blood vessels, lymph vessels, and nerves, form a primary lobule

In 1892 I published a paper in which I identified and described, for the first time, an atrium the work being done in the laboratory of the late Professor F P Mall, at that time connected with Clark University, Worcester, Massachusetts This was followed in 1893 by a more detailed description basing the account on a reconstruction, from serial sections, of the ultimate air spaces in the lung of a dog This study was repeated, with additional observations on the lymphatics, while working in the laboratory of Professor Werner Spalteholz in Leipzig, in 1896–97 (See *Handatlas der Anatomie des Menschen*, Leipzig, 1914 Bd iii Fig 624, also *Archiv f Anat u Physiol*, *Anatom Abthl* 1900) After my return to the United States, reconstructions were made from the lung of the cat, a man forty seven years old and a nine week-old child In each instance I found the same arrangement of the ultimate air spaces as I found in my original reconstruction from the lung of the dog Naturally, there was a variation in the size of the primary lobule, the [illegible]

the air spaces connected with it, brought out several interesting points The bronchiolus divided into two branches, bronchioli respiratorii, bearing scattered alveoli, one of these branches was carried out in detail After a short course it divided into two

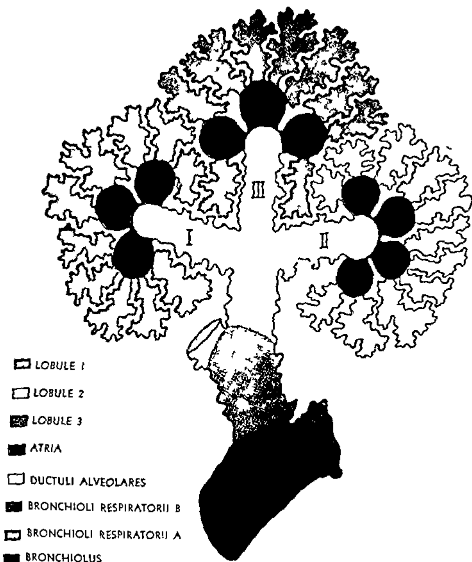


Fig 30—A purely diagrammatic representation of the portion of the lung entering into the reconstruction It shows schematically the method of branching of the bronchi the number of atria arising from each ductulus alveolaris and the sacculi alveolares connected with each atrium The sacculi alveolares of each lobule are differently colored so that they may be readily distinguished

branches which bore a greater number of alveoli than the one from which they had their origin Only one of these latter branches entered into the reconstruction This divided into three branches, the ductuli alveolares, each ductulus alveolaris gave origin to a series of atria and each atrium had a variable number of sacculi alveolares connected with it (Fig 30)

The reconstruction demonstrated two orders of bronchioli which bore alveoli before giving origin to the ductuli alveolares, these were designated as bronchiolus respiratorius a, and bronchiolus respiratorius b Later studies of the human lung have shown that this is a common occurrence, and that, in a few instances, there may be a third order of bronchioli respiratorii before reaching the ductuli alveolares

These subdivisions of the bronchioli respiratorii have been noted by other investigators of the finer ramifications of the bronchial tree D Hardiviller says that each bronchiolus respiratorius divides into two or more canals which show, on their part, several bifurcations

With the possible exception of Flint, none of the investigators who have studied the smaller bronchi seem to have found anything but dichotomous branching It is certain, however, that in the portion of the lung of the cat entering into the reconstruction,

practically the same size and length arise Two of these ductuli alveolares have each three atria attached to them, while the third has four, of the ten atria four have two sacculi alveolares arising from each, three have each three sacculi alveolares attached to them, two have four sacculi alveolares each, while one has five

It seems to me that, in a certain degree it conforms to the statement of Flint that there may be alternation of the two processes, dichotomy and monopody

Recurrent sacculi alveolares that is sacculi that are situated parallel, or nearly parallel, to the ductulus alveolaris from which they originated, were found in the lung of the dog and also in that of the cat

A special study was made from the lung of the forty-seven-year old man to demonstrate an atrium, its form and connections

In Figure 31 a bronchiolus respiratorius is seen dividing into two ductuli alveolares The one at the right is carried out, but the



FIG 31 —Reconstruction from the lung of a man forty seven years old For descr pt on see text ×?50 and reduced to 100

one at the left is left incomplete It will be seen that the bronchiolus at the right has at its distal end a slight dilatation In my original paper published in the *Anatomischer Anzeiger* in 1892 this dilatation was termed a vestibule By some authors notably Ogawa Wilson and others, this has been mistaken for an atrium Wilson goes so far as to say that the dilated end of Waters' terminal bronchial tube is identical with an atrium This is far from the

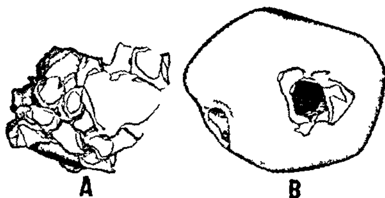


Fig 32—Reconstruction of atrium 2 in Figure 31 A negative model

air spaces was that I found the term already used by many of the French authors for an entirely different portion of the air tube, and its continued use would be confusing

Returning to the model Leading out from the dilated end of the ductulus alveolaris there are two openings which lead into the atria that enter into the reconstruction An opening is seen at the bottom of the ductulus alveolaris this leads into an atrium which is situated below the level of the reconstruction Of the two ...

atrium there is a single sacculus alveolaris which has been reconstructed A second sacculus which is situated below the level of the model is not seen a small portion of the opening leading to ...

sacculus is noted at the bottom of the atrium Another sacculus is situated above the level of the reconstruction Now, if the model be considered as a whole, *it will be seen that there is a direct connection between the bronchiolus respiratorius, the ductulus alveolaris the atrium and the sacculus alveolaris, and, viewed as an independent structure it would appear as though this were one continuous space* But when the upper portion of the model is placed upon it the openings leading from the atrium into the ductulus alveolaris and into the sacculus alveolaris are shown to be circular, or nearly

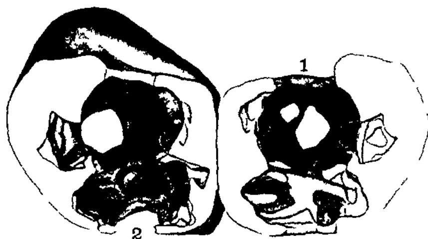


FIG 33—B in Figure 32 cut open showing the internal structure of the atrium 1 Opening from the ductulus alveolaris into the atrium 2 Opening … n Figure … ttom of

circular, in outline, by means of them the atrium, which corresponds to atrium 2 in Figure 31 is differentiated on the one hand from the sacculus alveolaris and on the other from the ductulus alveolaris The atrium leading to the right *is not carried out in a* separate reconstruction, but one can see that it has practically the same size as the atrium which is reconstructed and that there *are two sacculi alveolares* leading off from the single atrium Other sacculi alveolares are situated at a higher level in that part of the reconstruction which is not shown

An independent reconstruction was made of the atrium indicated in Figure 31, 2 in order to bring out more clearly its form and relationship Positive and negative models were made of the same atrium not a positive from one lung and a negative from another

lung and of different amplifications, as was done by Ogawa but the same sections and amplifications were used for each model A negative model which corresponds to a corrosion is preferred by many, but a positive model gives a far better idea of lung structure The two should, however, be studied simultaneously If one desires to know how the rooms of a house are arranged he does not depend on viewing the outside of the house or studying the arrangement

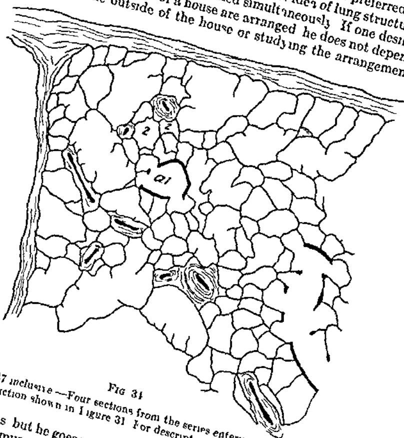


Fig 31

Figs 34 37 inclusive —Four sections from the series entering into the reconstruction shown in Figure 31 For description see text ×25

of the windows but he goes in notes the arrangement of the rooms how they communicate with each other and such other details as cannot be seen from the outside It is for this reason that the positive model is superior to the negative in the study of the air spaces for one is able to see how they are arranged and their communication

In Figure 32 the negative of atrium 2 Figure 31 is shown viewed from above It shows that the opening leading into a sacculus alveolaris is hidden by the portion of the sacculus which forms

the top section in Figure 32 a Figure 33 shows the positive from which Figure 32 was made Now if this were a portion of a complete corrosion the atrium could not be seen for it would be so obscured by the sacculi arising from it that it would be impossible to recognize it

In Chapter XI it will be shown that many of the older, and some of the modern, investigators based their descriptions of the lung on sections which included as many as possible of the air

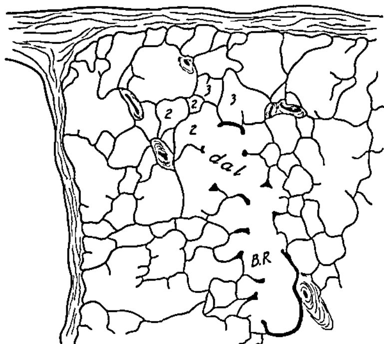


Fig 35

spaces in a single section (termed ' ideal longitudinal sections' by some investigators) For this reason the reconstruction was dissected in such a manner that some of the ultimate air spaces and their bronchial connections were exposed (Fig 31)

In order that the relation of the various air spaces shown in the reconstruction may be better understood and to demonstrate more clearly the relations of the atria camera lucida tracings were made of typical sections

In Figure 34 a', an opening is seen marked out by heavy out lines This leads into an atrium that is situated above the level of the section Following the air spaces toward the lower right corner of the section a chain of small air spaces (alveoli) can be recognized These are sections of alveoli which open into the underlying *ductulus alveolaris* and *bronchiolus respiratorius* The heavy out

lines on the right side of the section mark out the walls of a *bronchiolus respiratorius* that belongs to another system of air spaces

Figure 35 is an outline of a section taken 200 micra below figure 34 and shows not only the *ductulus* with which atrium a^1 communicates but also a portion of the *bronchiolus respiratorius* from which the *ductulus arises* Only a reconstruction from serial sections will

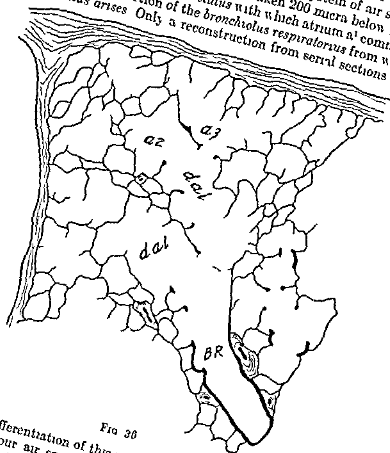


Fig 36

bring out a differentiation of this nature Around the distal end of the *ductulus* four air spaces (a^2 a^2 a^3 a^3) are indicated These belong to two atria with corresponding numbers which are connected with the ductulus at a lower level

Figure 36 is taken 200 micra below Figure 35 and shows the *bronchiolus respiratorius* cut lengthwise and the two *ductuli alveolares* into which it divides The openings by which atrium a^2 and atrium a^3 communicate with the *ductulus* appear in this section Two sacculi alveolares open out of atrium a^3 but none of the sacculi belonging to atrium a^2 are connected with it in this section

Figure 37 is from a section taken 200 micra below Figure 36 The opening by which atrium a^2 communicates with a sacculus alveolaris is cut through and a small portion of the opening by which the atrium communicates with its *ductulus* is shown Three alveoli (a^3 a^3 a^3) which belong to the atrium bearing the same number are seen just at the right of atrium a^2 Only a small portion

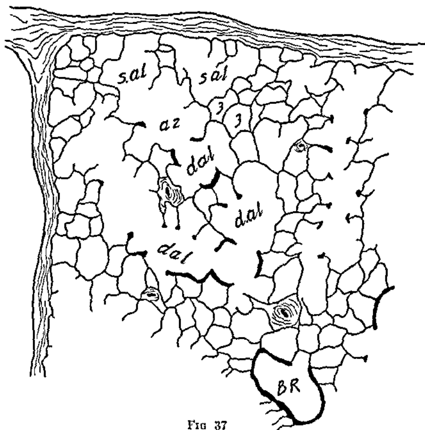


Fig 37

of the *ductulus alveolaris* which we have been considering remains while the *ductulus* which first appears in Figure 36 is shown cut through its entire length also a small portion of an atrium and sacculus alveolaris which are directly continuous with its axis A very interesting series of air spaces is seen on the right side of the section and they furnish a good example of the necessity of serial sections in studying the architecture of the lung These spaces belong to a still different system and are continuations of the *bronchiolus respiratorius* of which a small portion appears on the extreme right of the section

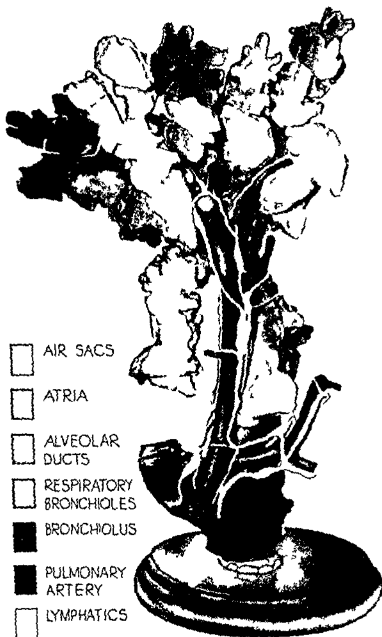


FIG 38 —Reconstruction from the lung of a nine week-old child On the left side of the model a recurrent *bronchiolus respiratorius* with its sub sequent subdivisions can be seen ×80

The reconstruction of the air spaces in the lung of the nine week-old child shows the same arrangement as the lung of the adult man, and in addition it demonstrates that there may be not only recurrent atria and sacculi alveolares, as in the reconstructions



FIG 39 —Outline of a section above the level of the bronchiolus respiratorius shown in Figure 38 The heavy outlines indicate the position of smooth muscle The pulmonary artery and its branches are in solid black Branches of the pulmonary vein are indicated by cross hatched areas lymphatics by stippled areas ×80

from the lung of the dog and cat but there may also be recurrent bronchioli respiratorii with their ductuli alveolares and the atria and sacculi belonging to them (Fig 38)

The model of the nine-week-old child is a *negative* model I have used it to demonstrate that corrosions (for it corresponds to a corrosion), when studied alone, fail to give a true picture of lung structure In order to bring out the atria and their sacculi alveolares it was necessary to study the positive model and make the necessary dissections of the negative to show to the best advantage the relation of the air spaces to each other

Figure 39 is an outline of one of the sections above the level of the bronchiolus respiratorius Taken by itself it would be difficult to interpret it correctly but studied in connection with the model it presents no difficulty

In the bronchi the bronchioli and the ductuli alveolares, the elastic fibers run parallel to their long axis (Fig 40) Branches are given off which pass to the bands of smooth muscle in their walls surround them with a network of fibers and then take part in the formation of the outer fibrous tunic In the atria the sacculi alveolares and the alveoli the elastic fibers form an intricate network About the openings leading from the ductuli alveolares into the atria from the atria into the sacculi alveolares (Fig 41) and from the sacculi alveolares into the

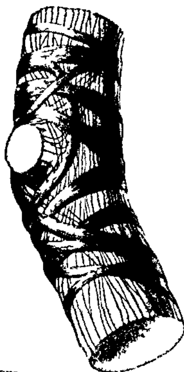


FIGURE 40 shows the arrangement of the elastic fibers and the smooth muscle bands at the place where a branch is given off from a main stem bronchus Note that the elastic fibers in general have a longitudinal course but at the point where the branch leaves the main stem bronchus they swing over to the opposite side of the bronchus and in that way they encircle the branch as it leaves the main stem bronchus On the other hand the smooth muscle bands also have a triangular arrangement about the place where the branch leaves the main stem bronchus By this arrangement the triangle which is formed by the interlacing of the smooth muscle bands is filled in by elastic fibers and at the same time the triangular area left by the crossing of the elastic fibers is filled in by the interlacing of the smooth muscle bands Note the way in which the elastic fibers leave the main stem bronchus and are arranged on the branch

Fig 41 —A sacculus alveolaris cut off from its atrium showing the arrangement of the elastic fibers Note the encircling band of elastic fibers at its junction with the atrium, and the network of fibers which enclose the sacculus Semi diagrammatic

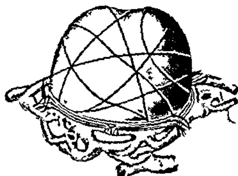


Fig 42 —Network of elastic fibers surrounding and enclosing an alveolus Red elastic fibers Blue capillaries Semi-diagrammatic

alveoli (Fig 42), the elastic fibers are arranged in an encircling band of interlacing fibers From these bands individual fibers are given off which branch and anastomose to form a network of fibers which are derived, in the case of the atria, from the fibers in the ductuli alveolares, in the case of the sacculi alveolares, from the fibers in the atria, and in the case of the alveoli, from the sacculi alveolares

If the atria, the sacculi alveolares, and the alveoli are considered as distensible bladders enclosed by an elastic network, it will appear that, as they are distended with air, the elastic fibers in the bronchioli and ductuli alveolares are put on the stretch in a longitudinal



Fig 43 —Reticulum in the alveolar walls At the extreme left of the figure a bundle of collagenous fibers may be seen ×500

direction, while the network in the walls of the atria, the sacculi alveolares, and the alveoli is also put on the stretch From the nature of the network they are capable of distention in all diameters, but their relative shape is preserved by the encircling network of ibers In the case of the bronchioli respiratorii and ductuli alveolares the bands of smooth muscle prevent any over-distention Figs 20, 21)

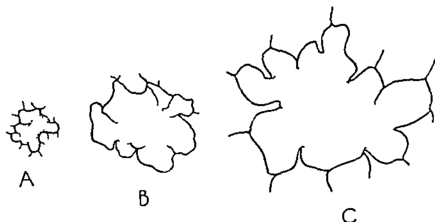
The walls of the sacculi alveolares are composed of blood capillaries (which will be described in the section on the blood vessels),

elastic fibers reticulum, a few strands of collagenous fibers and epithelium

The elastic fibers form a network which occupies a central position in the wall of a sacculus alveolaris In the angle formed by the union of two or more sacculi alveolares the elastic fibers have a complicated arrangement by means of which the sacculi are strongly united

The reticulum is situated external to the elastic fibers and forms the basement membrane on which the epithelium rests it is closely associated with the capillaries about which it sometimes forms a network When seen on the flat surface of the wall of a sacculus it has the form of a loosely woven network (Fig 43)

Collagenous fibers are best seen where pre capillary blood vessels are cut transversely in the angle formed by the union of two or more sacculi



... to the age and
... size of
A from
... adult

It is questionable whether nerve fibers are present in the walls of a sacculus Since occasional smooth muscle cells have been described in the walls of the capillaries it is not unreasonable to assume that nerves may also be present but they have not as yet been demonstrated in a satisfactory manner

An interesting study is that of the dimensions of the various air spaces within the lung I have not been able to complete a series of measurements begun some time since In order to arrive at anything like a correct statement many hundreds of measurements

should be made of lungs of different degrees of distention and from individuals of different ages The points between which measurements should be taken should be determined, for a distinction must be made between *sacculi alveolares* and *alveoli pulmonum*

Figure 44 illustrates some of the difficulties of the problem The sections are taken transverse to the sacculi, the spaces included within the dotted lines are to be considered as belonging to the sacculi, while the irregular spaces lying outside of the dotted areas are *alveoli* No doubt marked difference in size exists between superficial sacculi and those more deeply situated, and, possibly, between alveoli in different lobes of the same lung

The best table of measurements with which I am acquainted is that of Rossignol, he does not, however, give the points between which the measurements were taken It seems to me that further study along the lines indicated above will give different results from those obtained by Rossignol

Alveolar Epithelium. The presence or absence of an epithelium lining the walls of the pulmonary alveoli has been a much discussed subject While at first the presence of an epithelium was strenuously denied, later investigations, although they did not agree as to the character of the epithelium, did agree that an epithelium was present The subject has recently been re-opened by the denial of any epithelial lining of the alveolar walls other than the non-nucleated plates of Kolliker

It is now over eighty years since the subject was brought to the attention of both normal and pathological histologists by the papers of Thomas Addison I do not find any direct statement in regard to alveolar epithelium in his first paper (1837), but in a later publication (1843) he disagrees with Reisseisen and others who say "that the air cells are merely the blind extremities of as many bronchial tubes, and that, like the latter, they are lined by an ordinary mucous membrane," thus implying the absence of any epithelium

In his study of the membranous walls of the air cells, William Addison (often confused with Thomas Addison) found that "they possess an epithelium in the form of large, round, nucleated scales, and from one to fifteen or more nuclei may be counted in a single scale I have never satisfied myself that they possess the ciliated cylinder epithelium so abundant in the trachea and the bronchi "

Williams confirmed the observation of William Addison, but Rainey denied the presence of any epithelial lining to the alveolar walls and the long contest regarding the presence or absence, and, eventually, the kind of epithelium present, was under way Oppel

gives a long but not always accurate analysis of the various opinions

Eventually the contest narrowed down to the question of a continuous layer of squamous epithelium or one made up of large non nucleated plates interspersed with islands of small nucleated cells Chrzonszczewsky supported the former Kolliker in his 1881 paper the latter arrangement Of the two opinions that of Kolliker has up to the present time received the support of the majority of investigators

It will be necessary to review briefly the investigations of Eberth Chrzonszczewsky and Elenz *on the alveolar epithelium of the* higher vertebrates and of Colberg on the human fetal lung before considering the work of Kolliker for their results paved the way for Kolliker

Eberth described islands of epithelium that occupied the mesh of the capillary network but did not extend over the capillaries these being covered by a structureless membrane His studies formed the groundwork for the continuance of his investigations by Elenz one of his students

Chrzonszczewsky criticizing the technique of those investigators who denied the presence of an epithelium lining the alveoli says In all these instances the fault evidently lies not in the lung but in the method

As the result of his studies Chrzonszczewsky found not only in sections taken just beneath the pleura but also in sections taken *from the deeper portions of the lung* that the alveoli were lined with a complete uninterrupted layer of delicate cells which had a polygonal outline Oppel says that in Chrzonszczewsky s illustration the cells are too uniform in size and that the nuclei are always in the center of the cell a criticism that seems *trivial since* the drawing is apparently an attempt to represent diagrammatically what he saw and he saw correctly

Elenz went a step further the
same islands of epithelium
found that the structureles
extending over the capillaries was made up of large irregular membranous non nucleated plates By this statement Elenz became the predecessor of Kolliker in ascribing to the alveolar *walls* two types of cells groups of small nucleated cells and large non nucleated plates

Elenz criticizing the work of Chrzonszczewsky said *that his* illustration demonstrated that it was the pleural mesothelium and not alveolar epithelium that he had stained In reply Chrzonszczewsky said and correctly that the two in no way *resembled* each *other* and pointed out that Elenz had correctly described and [illegible] between the two types of cells

Colberg studied the alveolar epithelium in human fetal lungs and found that with the growth of the fetus the epithelium increased only in width and that the cells eventually fused to form an uninterrupted complete "membrana epithelica" in which only



FIG 45—An alveolus with respiratory epithelium a a lines which extend from small pavement cells into large plates and indicate their divisions b b a second form of such dividing lines c c small non nucleated plates d d same type of plates not completely surrounded by dividing lines (Kölliker's Fig 10) ×352

the nuclei of the previously existing cells could be recognized That Colberg failed to demonstrate the cell boundaries is not surprising for it is a difficult problem even with modern technique In his paper published in 1866 he sums up his studies as follows Pathological and comparative anatomical facts show that

spite of nearly constant negative results a complete epithelium must also exist in the adult human lung

Kolliker like Elenz describes the alveolar epithelium as consisting of two distinct types of cells small nucleated flat rounded polygonal cells which occupy the mesh of the capillary network and large variously formed apparently non nucleated very thin plates which rest upon the capillaries but can also extend over their mesh

His study was made on a lung which was removed from a criminal *half an hour after his execution* The lung was injected through the bronchi with a weak solution of silver nitrate and then placed in a 0 5 per cent solution of the same salt This stained only the pleural mesothelium and some of the superficial alveoli The lung was next placed in alcohol and some months (*sic*) later sections were cut and exposed to the light

Any one who has had much experience trying to obtain satisfactory stains of the alveolar epithelium with nitrate of silver can readily understand how uncertain its action can be and Kolliker s *illustrations are good examples of its* irregular action (Fig 45)



Fig 46—*The swollen epi*thelium along an alveolar wall (see text) ×500

With the general acceptance of Kolliker s description of the alveolar epithelium all investigation of the alveolar epithelium practically ended *and his illustrations are frequently reproduced*

In a recent publication Lang goes a step beyond Kolliker and denies the presence of any epithelium except the non nucleated plates on the alveolar walls He describes a special cell which he calls a septum cell I am yet to be convinced that this is anything but an *alveolar epithelial cell* which has changed its form through imbibition of fluid or possibly *it may be a mononuclear leucocyte* which has undergone the same process

*The great obstacle to a correct under*standing of the alveolar epithelium is the inability to dissect off the epithelial layer or to remove it by any artificial means Colberg tried in vain to isolate his membrana epithelica *and other* investigators have had the same ex*perience*



FIG 47.—Three sections from a series which show on their upper side the epithelium slightly raised from the surface of the alveolar wall by the exudate behind it These sections are described in detail in the text ×500

As the pathological histologist is obliged at times to turn to normal tissues so the normal histologist is obliged to turn to pathological tissues to obtain a better insight into the material under observation What Colberg and other workers could not accomplish is often accomplished by pathological processes Through the pouring out of a serous exudate behind the alveolar epithelium in a pneumonia or in the mechanical edema of mitral stenosis with insufficiency of the valves the *vis a tergo* pushes off the epithelium



a X300

ed
sli
due to the imbibition of the serous exudate In various places on each side of the alveolar wall epithelial cells are overlaid by other epithelial cells this gives them the appearance of having two nuclei The sections of the capillaries and their relation to the epithelium are interesting The capillary near the center of the section has on its right the nucleus of an epithelial cell while on its left there is the thin expanded part of an epithelial cell

Eberth Elenz Schulze and Kolliker state that only the non nucleated plates cover the capillaries a statement which this and numerous other sections show to be incorrect In the upper portion of the section two other capillaries appear the lower of the two contains a mononuclear leucocyte turned up edgewise while the upper one shows an endothelial nucleus cut transversely

In order to show the relation of the nucleus to the thin expanded portion of the cell and the changes in the appearance of the same epithelial cell at different levels three sections from a series are shown in Figure 47 The sections are 7μ in thickness and between a and b and between b and c a section has been omitted on account of its being stained for the reticulum These three sections represent therefore 35μ of the alveolar wall More sections could have been used but they would only have repeated what is shown in these three

The amount of the serous exudate is greater in Figure 47 than in Figure 46 and as a consequence the cells are pushed further away from the alveolar wall Some of the cells especially on the left of Figure 47 a have absorbed a considerable quantity of fluid and are assuming a spherical form As soon as a chain of these cells breaks apart the individual cells float into the lumen of the alveolus and become the large round cells so frequently seen

In Figure 47 b some of the cells show either the lower or the upper edge of nuclei which are cut nearer the center in a or in c In Figure 47 c in which individual cells are well shown the spindle shape of the cells before any considerable amount of fluid is absorbed is clearly shown

When these three sections are considered as a whole they point to the fact that in the normal lung the epithelium lining the alveolar walls is made up of thin flattened nucleated squames which are closely applied to the alveolar wall and that it is a continuous epithelium

Figure 48 is from the same series as Figure 47 but is from an alveolus some distance from the one shown in Figure 47 Along the upper border of the section the cells have been pushed off some distance from the alveolar wall while on the under side most of the cells are still *in situ* though somewhat swollen Here again evidence is shown that it is a continuous nucleated epithelium that lines the alveolar walls

[illegible] illustrating [illegible] walls by the [illegible] pneumonia (Fig 49) The epithelium lining the alveolus in the center of the figure has been pushed off as a complete and continuous sheet Certain of the cells have absorbed a larger quantity of fluid than others consequently they have assumed a more spherical outline

The alveolus in the upper right quadrant of Figure 49 is of even more interest Along the lower border of the alveolus the epithelium has been pushed off from the alveolar wall and the cells show a moderate degree of swelling As these cells are followed

around the left side of the alveolus, it can be seen that the epithelium is closely applied to the alveolar wall and that the nuclei show but faintly. In other words, on the left side of the alveolus the epithelium is in its normal position, a thin, continuous sheet with its nuclei like the cells themselves, stretched out and staining faintly, while along the lower border the epithelium has been pushed off the alveolar wall by the exudate. The epithelium in the other alveoli also shows interesting stages in the position and form of the cells.

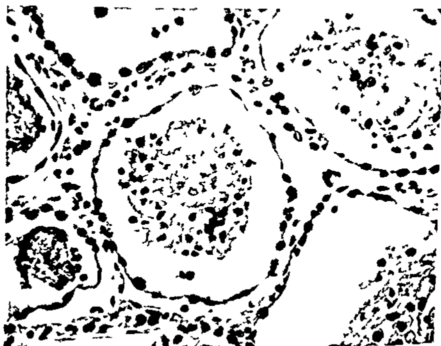


FIG. 49.—The epithelium lining the alveolus in the center of the figure has been pushed off as a continuous sheet. Certain of the cells are more swollen than others. The alveolus in the upper right of the figure shows clearly the epithelium before and after an exudate has raised it from the surface of the alveolar wall. For a further description of the figure see the text. ×315.

In Colberg's 1866 paper there is an illustration similar to Figure 49. I had not seen this at the time I published my paper in *The Journal of Experimental Medicine* (1925), and I take this opportunity of calling attention to it. His conclusion that "pathological and comparative anatomy facts demonstrate that in spite of constant negative statements, a continuous epithelium must exist in the alveoli of adult human lungs" is as true today as at the time he wrote.

Not infrequently, imperfect sections show a given point to better advantage than perfect sections. In a section through a bronchiolus of an imperfectly distended lung, the somewhat 'demoralized' section (Fig 50) shows the epithelium torn off as a continuous sheet along the upper wall of the larger alveolus, while the few cells in the alveolus at its right show, by their cuboidal shape that the lung is partly collapsed, for in sections taken through an atelectatic area of a lung, the alveoli are found to be lined with a continuous cuboidal epithelium and only the absence of smooth muscle prevents their being mistaken, in many instances, for sections of bronchioli. Here again, the evidence points to a continuous epithelium lining the pulmonary alveoli.

Alveolar Reticulum The epithelium of the alveoli like that of the bronchi and bronchioli, rests upon a network of reticulum (Fig 51). The alveolar epithelium stains more faintly with Biel-

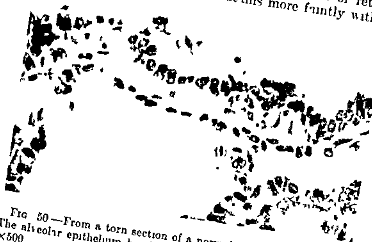


Fig 50—From a torn section of a normal partly collapsed lung. The alveolar epithelium has been pulled off as a continuous sheet ×500

schowsky's stain than the epithelium of the bronchioli but here and there along the alveolar walls as marked out by the reticulum, an epithelial cell with its nucleus can be seen. In other places the faint outlines of epithelial cells appear. The upper wall of the smaller of the alveoli has been cut obliquely, and the network of reticulum in its wall is indistinctly shown. In the lower wall of the same alveolus a transverse section of a capillary with an epithelial cell just outside its wall, can be seen.

Alveolar Pores Alveolar pores must not be confused with the wide-open communication described by the early writers on pul-

monary structure Alveolar pores can be defined as minute openings in the walls of the alveoli of the normal lung

Adriani in 1847 was the first to describe as normal structures, these openings by which an alveolus communicated with an adjoining alveolus In 1850 Schultz followed in 1852 by Kolliker denied that they were present in the normal lung Later investigators can be divided into three groups

(1) Those who deny their presence in the normal lung
(2) Those who insist that they are normal structures
(3) Those who say that they exist but that they are the result of pathological processes

The first group includes Waters Turner Aigner Miller v Ebner Merkel and Oppel F E Schulze can also be included in this group since he maintains the independence of the alveoli and alveolen gange

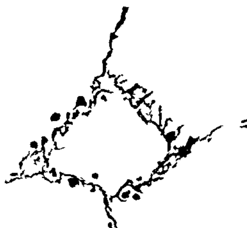


Fig 51 —Reticulum in the walls of an alveolus A few epithelial cells can be seen *in situ* ×500

The second group comprises Hansemann Hauser Nicolas Braus and Zimmermann Of these Hansemann is the most strenuous in the defense of his position basing his statements on the fact that after injecting a blue gelatin solution containing a large volume of water and placing the lung immediately in alcohol minute threads of gelatin could be seen due to the shrinking of the gelatin passing through the alveolar walls and connecting the gelatin in one alveolus with that in adjoining alveoli

By using a gelatin containing a minimal amount of water Aigner found after fixing the lung in various fluids a complete absence of the threads described by Hansemann as passing through the alveolar walls the alveoli being uniformly filled with the gelatin with no irregularities in the contour of the gelatin

The third group consists of Henle Toldt Kohn Ribbert Herbig Bezzola and Miller Henle described circular sharp bordered openings in the walls of adjoining alveoli but attributed them to the atrophy and resorption of the lung substance in mature indi

viduals In other words he considered them the result of a pathological process Although Ribbert did not have a correct idea of the form and arrangement of the epithelium lining the alveolar walls he did correctly ascribe the formation of pores to the shedding of the epithelium in this he was supported by the investigations of Herbig and Bezzola

Kohn found in cases of pneumonia that fibrin threads could be traced through minute openings in the alveolar wall from an alveolus into the adjoining alveolus He did not consider these openings normal structures but the result of the pathological process

For the study of alveolar pores silver stains have been quite generally used Any one who has used silver solutions to demonstrate epithelial boundaries realizes the uncertainty of their action A notable example of this has been discussed in connection with Kolliker s study of the alveolar epithelium

Figure 52 which is reproduced from Merkel shows two so called Lockern from the lung of the cat stained with silver The large clear space is undoubtedly due to a shed epithelial cell while the smaller one has been caused by the slight shrinking of an epithelial cell The incomplete action of the silver is shown by the broken lines which probably formed part of the boundary lines of other cells



Fig 52 Alveolar wall from the lung of a cat which had been injected with a solution of silver See text (After Merkel)

Pathologically the question whether pores are present in the normal lung is of much interest In the section dealing with the epithelium of the alveoli it was pointed out that much in regard to the normal structure of the lung can be gained from a study of pathological material So for the study of alveolar pores pathological material is best used For this purpose sections from cases of lobar pneumonia and mitral stenosis with insufficiency of the mitral valves give interesting results in the first case we are dealing

thelium which is pushed off from the alveolar walls by the *vis a tergo*

Shedding of the epithelium constitutes but one step in the for



Fig 53.—From a case of lobar pneumonia The exudate has found its exit from a very definite point and has been converted into fibrin which radiates into the alveolus No pore has resulted because the epithelium on the opposite side of the alveolus is still intact ×800

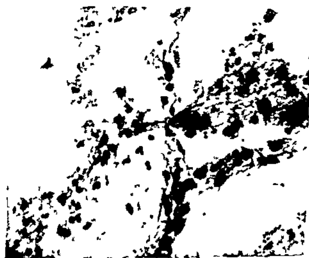


Fig 54.—From the same series as 53 The epithelium has been pushed off from diametrically opposite sides of the alveolar wall and a pore has been formed with a thread of fibrin passing from one alveolus to an adjoining alveolus ×400

mation of a pore If the epithelium on the opposite side of the alveolar wall remains intact then no pore can result from the shedding of the epithelium on one side of an alveolar wall The epithelium on diametrically opposite sides of an alveolus must be shed in order that a pore may be formed The epithelium being pushed off from diametrically opposite sides of an alveolar wall the serum poured out from the capillaries now finds an exit into adjoining alveoli and with the conversion of the fibrinogen into fibrin the characteristic strands of fibrin passing through the alveolar walls are produced

In Figure 53 taken from a case of lobar pneumonia the exudate has escaped from a definite point and the epithelial cells can be seen attached to the strands of fibrin as they leave the alveolar wall Although the epithelial cells on the opposite side of the alveolar walls from which the exudate has escaped are somewhat swollen they are still intact The amount of exudate is large but the injury to the alveolar wall is of such a nature that no pore has been formed

In Figure 54 the epithelium has been shed from diametrically opposite sides of the alveolar wall and a pore has been formed and threads of fibrin can be seen passing from one alveolus to the adjoining alveolus

In the mechanical edema due to mitral stenosis with insufficiency of the valves there frequently occurs extensive shedding of the epithelium on both sides of the alveolar wall which allows the serum to escape freely into adjoining alveoli It is on account of this extensive shedding of the epithelium and the absence of fibrin threads to act as guides that pores although they may be present in large numbers are difficult of demonstration

Alveolar pores therefore are *not* to be considered normal structures but the result of some pathological process which occasions the shedding of the epithelium on diametrically opposite sides of an alveolar wall

Th

have another explanation for the cell found along the alveolar walls To quote an opposite opinion Lang calls certain cells seen on the surface of the alveolar walls septum cells He further says that septum cells may under the influence of various normal and abnormal stimulations appear as alveolar phagocytes as dust cells or exudate cells He was unable to find any respiratory epithelium on the walls of the alveoli On the other hand

Max Clara, who designates these cells "epicytes," says "All histogenetic, histobiologic and pathologic findings speak for the origin of the epicytes (Deckzellen) of the glomerulus of the kidney, and of the alveoli of the lung, from the originally existing epithelium." In other words, the epicytes are modified epithelial cells

At the 1936 meeting of the American Association of Anatomists the presence or absence of a continuous epithelium lining the walls of the pulmonary alveoli was the subject of a round table confer-

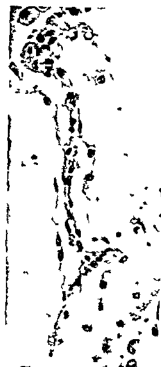


Fig 55—Section of an alveolar wall from which the epithelium has been pushed off on each side by an exudate ×400



Fig 56—An alveolus situated just beneath the pleura lined with cuboidal epithelium From a case of bronchopneumonia ×450

ence The chairman of the conference, Professor Charles C Macklin, in his report stated

Though no conclusions were drawn by the Conference it is hoped that the focusing of attention upon the points at issue will have the effect of stimulating efforts which will result in the bringing out of new evidence For instance if there is no alveolar epithelium [as stated by Lang] there must be a region on the airway where the epithelium of the bronchial tree comes to an end There must be a "free edge" somewhere The old idea of a non nucleated "plate" is disappearing

Macklin also stated that a number of those taking part in the discussion said that they were unable to demonstrate the presence of

an epithelium I can sympathize with them it took me many years to find that the material and methods of study usually employed were useless This led to the use of pathological material in the hope that a clue could be found that would assist in the solution of the problem

Such a clue was found in the section shown in Figure 49 While the alveolus in the center of the photograph is interesting the alveolus in the upper right quadrant is of especial interest If the reader will turn back to page 57 and read the paragraph describ



Fig 57 —Tangental section of an alveolus from the same series as Fig 56 ×450

thelium on the left side of the alveolus is still spread out as a thin sheet, closely applied to the alveolar wall, while the epithelium on the opposite side of the alveolar wall has been pushed off by an exudate Figure 55 is a photograph of a section in which the epithelium on each side of an alveolar wall has been pushed off by an exudate In each instance it is a sheet of thin, flattened cells that has been raised from the alveolar wall and not a membrane formed on the surface of the alveolar wall as some would have it

When an exudate removes pressure from the epithelium, or throws it out of function there is a return of the cells to the cubical

form seen in the atelectatic fetal lung The following figures illustrate this point

Sections taken through the pleura and the underlying alveoli from a case of bronchopneumonia show the alveoli lined with a

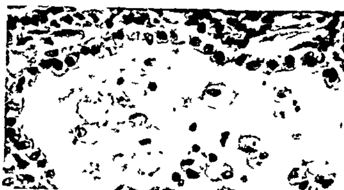


Fig 58 —Section of an alveolar wall situated deep within the lung showing the same type of epithelium lining its wall as is seen in Fig 56 From a case of Hodgkin's disease ×450



Fig 59 —From a case of interstitial pneumonia The alveoli are lined with cuboidal epithelium ×150

continuous layer of cuboidal epithelium (Fig 56) A cluster of cells in an alveolus cut tangentally from the same series as that from which Figure 56 was taken, shows the characteristics of cuboidal cells cut transversely (Fig 57)

In Figure 58, taken deep within the lung from a case of Hodgkin's disease, an alveolus is seen lined with the same type of epi-

thelium as is seen in Figure 56 Still more impressive is Figure 59, taken from a case of interstitial pneumonia Sections of atelectatic lungs show practically the same type of epithelium lining the alveoli

I realize that those who disagree with these conclusions will say "pathological" Granted—but in other instances, for example, the central nervous system, the normal histologists have learned much from pathology Marchand expressed his regret that pathological studies were often ignored, when he said, "Pathological studies are often helpful for a better understanding of normal findings and have indeed served that purpose"

In the fetal lung the pulmonary alveoli are lined with a continuous layer of cuboidal epithelium As respiration becomes established and the alveoli distended, the epithelium, still continuous, becomes stretched out so thin that the usual laboratory methods fail to demonstrate it In certain disease processes this thin translucent epithelium is pushed off from the alveolar wall by an exudate and, through the absorption of fluids, becomes distinct with well marked nuclei In other instances the epithelium returns to its fetal type of cuboidal cells

Shed epithelium is frequently seen in sections of the pulmonary alveoli That these shed cells are replaced through cell division is apparent by the frequency with which mitotic figures are found

Chapter V

THE BLOOD VESSELS

Arteria Pulmonalis. The arteria pulmonalis, the *vena arteriosa* of Galen, follows in all of its subdivisions the *subdivisions of the bronchial tree* As it arches over the main-stem bronchus it comes to lie posterior (dorsal) and slightly lateral to the bronchus At first

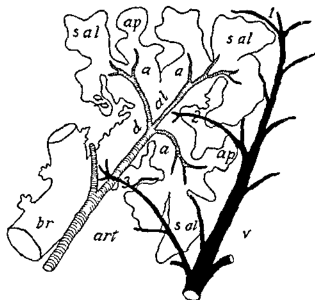
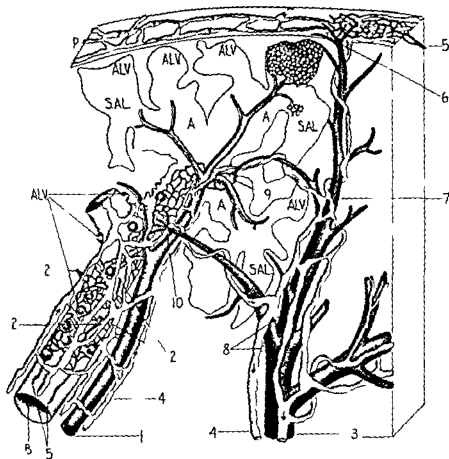


Fig 60.—Schematic longitudinal section of a primary lobule of the lung showing the relation of the blood vessels to the air spaces b r, bronchiolus respiratorius, d al ductulus alveolaris, a a a, atria, s al s al, sacculi alveolares, a p, a p, alveoli pulmonum, art arteria pulmonalis with its branches to the atria and the sacculi, v vena pulmonalis with branches from the pleura (1), from the ductulus alveolaris (2) and from the forking of the bronchiolus respiratorius (3) (After Miller 1900)

the artery and bronchus have nearly the same diameter, but the artery diminishes much more rapidly in size than the bronchus, so that by the time it reaches the lobule it is about one fourth or one-fifth the size of the ductulus alveolaris It is usually stated that the artery, as it approaches its ultimate ending, divides more frequently


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7

than the bronchus This would hold true for the old conception of the lung for no subdivisions of the bronchial tree were recognized beyond the distal termination of what is now known as the *ductulus alveolaris*

It has already been pointed out that the ductulus alveolaris gives rise to the atria, the atria to the sacculi alveolares, and that these collectively, with their blood vessels, lymph vessels and nerves form the lobule When the artery reaches a point distal to the

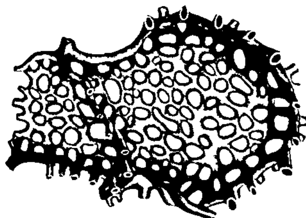


Fig 62 —Network of capillaries in the walls of the sacculi alveolares ×375

ductulus alveolaris, it breaks up into as many branches as there are *atria* (Fig 60) Sometimes we find a special branch given off from the artery just before it enters the lobule which supplies the more dependent of the sacculi alveolares Each of the atrial arteries after giving off twigs to the walls of its atrium, breaks up into as many branches as there are *sacculi alveolares* connected with the atrium Each sacculus artery gives rise to small radicles which run in the sulci between the *alveoli pulmonum* on the central* side of

* I use central to designate that part of the sacculus alveolaris which is nearest to the center of the lobule peripheral for that which is most distal

a

sources of
n the net-
work of capillaries into which the arteria bronchialis breaks up in the pleura 7 8 9 10
situations in which lymphoid tissue is found

the sacculus and end in a capillary network from which most of the *venae pulmonales* take their origin (Fig 61)

Capillaries The capillaries into which the arteria pulmonalis breaks up form within the lung the richest capillary network in the body, the mesh of which, as F E Schulze has pointed out, is exceedingly small often less than the diameter of the capillaries that bound it

From this capillary network venous radicles are formed which are situated on the peripheral side of the *sacculus alveolaris* opposite

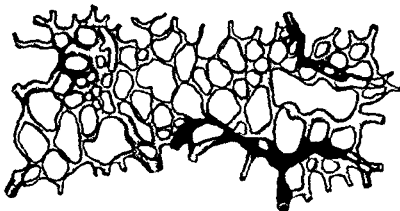


FIG 63 —Capillary network in the walls of two alveoli that abut against a small bronchiolus Note the coarseness of the capillary network as compared with the network in Figure 62 ×375

the artery From the last point where the arterial radicles can be recognized to the first point where the venous radicles can be distinguished there are usually twenty five or more capillary loops

This network of capillaries is situated within the walls of the *sacculi alveolares* and, as already stated, forms a part of them As Rainey pointed out only a single network is found in any given wall the network is therefore, common to two or more adjacent *sacculi alveolares* (Fig. 62)

The mesh of the capillary network in the walls of the alveoli situated just beneath the pleura is much coarser than that within the lung the proportion being nearly four to one, the same is true in the case of alveoli that abut against the connective tissue septa and to a lesser degree in the case of alveoli that abut against bronchi or blood vessels that are surrounded by dense connective tissue (Fig 63)

Venae Pulmonales The pulmonary artery closely associated with

the bronchus is often enclosed within the same connective tissue

ins the *arteriae venosae*

the bronchus and its

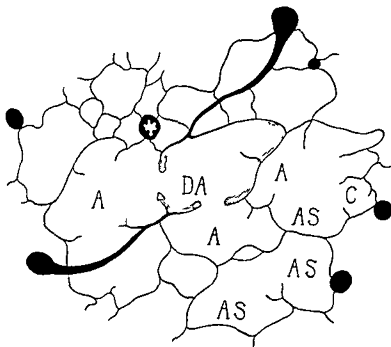


Fig 64 —Combination of three sections taken through the center of a primary lobule of the lung of a dog D A ductulus alveolaris A A A atria A S A S A S sacculi alveolares C alveolus pulmonis The tunica muscularis of the ductulus alveolaris is indicated by the broken lines The pulmonary artery is indicated by the vessel with a stellate opening the pulmonary veins are in solid black Note the two veins which arise from the ductulus alveolaris they correspond to (2) in Figure 29 Camera lucida drawing ×80

The pulmonary veins can be traced to four sources of origin

(1) The capillary network within the pleura which is derived in man and animals with a *thick* pleura from subdivisions of the *bronchial artery* *in animals with a thin pleura from subdivisions* of the pulmonary artery

(2) The capillary network in the ductuli alveolares which gives origin to two venous radicles one on either side of a ductulus As will be noted later these two radicles are the *only veins found* within the primary lobule and carry away blood from the ductulus and adjoining atria (Fig 64)

(3) The two venous radicles one on either side which leave the

bronchi at the place where bronchi or bronchioli divide (Fig 61) These venous radicles are sometimes called broncho pulmonary veins (Fig 69)

(4) The network of capillaries derived from the pulmonary artery situated within the walls of the sacculi alveolares (Fig 61)

In a transverse section through a primary lobule which includes the distal end of the ductulus alveolaris (Fig 64) it will be seen that the artery occupies a central the veins a peripheral position The two venous radicles which form the exception to the rule that the veins are peripheral can be seen one on either side as they leave the ductulus

Bronchial Artery The discovery of the bronchial arteries is usually ascribed to Ruysch who made claim to the honor in the following words *Hanc arteriam a nemine adhunc esse observatam intrepide affirmo* ' He was not however the first to see them Galen knew that the aorta sent small branches to the lung but he had no name for them Columbus denied their existence in the following words *Ab aorta arteria ramus nullus neque magnus neque parvulus ad pulmones mittitur* consequently they were forgotten until Dominico de Marchettis again described them He was therefore the second one to describe the bronchial arteries although Ruysch had claimed the primary honor for himself

The bronchial arteries vary in number and origin Usually three arteries are described one for the right lung and two for the left lung They ordinarily take their origin from the ventral side of the upper part of the thoracic aorta The right bronchial artery is more variable in its origin than are the left bronchial arteries it may arise from the first intercostal artery the third intercostal artery the right internal mammary artery or the right subclavian artery Occasionally all three arteries arise from a common trunk which has its origin on the ventral side of the thoracic aorta Both sets of arteries pass along the posterior wall of their respective bronchus and enter the hilum of the lung

As soon as the bronchial arteries have entered the lung they embed themselves in the layer of connective tissue which surrounds the bronchi As a rule two or three branches of the bronchial artery accompany each of the larger bronchi and bronchioli and each subdivision of the bronchial tree is accompanied by a corresponding division of the bronchial artery

Anastomosing branches connect the arterial trunks with each other and in this way a plexus is formed which has a much elongated and irregular mesh The general cour e of the vessels which form this plexus is at a right angle to the muscular layer

Branches of the bronchial artery can be followed as far as the

smaller bronchioli With the appearance of alveoli along the walls of the bronchioli, the character of the air tubes changes, and the bronchial arteries, as a distinct set of vessels, disappear (Fig 61)

From the arterial plexus in the fibrous layer small branches are given off which penetrate the muscular layer, when they have

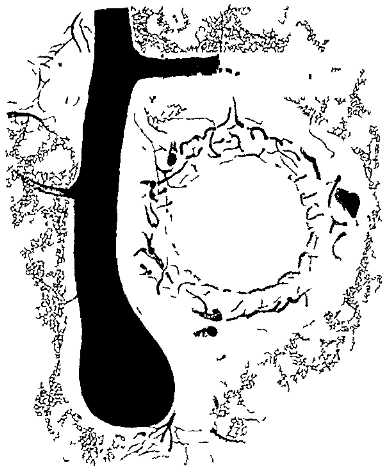


Fig 65 —Transverse section of bronchiolus 0 7 mm in diameter Bronchial arteries red, pulmonary vessels, blue ×60

reached the *tunica propria*, they turn and run for a short distance parallel with the muscle bundles, and then break up into capillaries which form a network, the long axis of which corresponds to the long axis of the bronchus

From this network of capillaries venous radicles arise, which unite to form a plexus with an irregular rectangular mesh, situated on the inner side of the muscular layer, from this plexus short

branches penetrate the muscular layer and form a second plexus of larger vessels along the boundary line between the muscular and fibrous layers From this second plexus small veins arise which form one of the sources of origin of the pulmonary vein (Fig 69) By this arrangement the muscular layer of the bronchi and of the bronchioli is situated between two venous plexuses

Taking up now in detail the distribution of the bronchial blood vessels, Figure 65 is a transverse section 100μ thick of a bronchiolus 0 7 mm in diameter The three principal branches of the bronchial artery (red) are nearly equidistant from each other Small

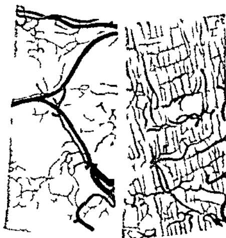


Fig 66—Dissection of a longitudinal strip of a bronchiolus Bronchial vessels red pulmonary vessels blue ×20

branches of the artery appear scattered about in the outer fibrous coat of the bronchiolus On the left side of the bronchiolus midway between the pulmonary artery (blue) and its lumen some of the branches of the bronchial artery can be seen which penetrate the muscular layer and eventually break up into the capillary network which is situated within the *tunica propria* of the bronchiolus A few of these capillaries can be seen as fine blue vessels on the opposite side of the bronchiolus running parallel to its long axis The two venous plexuses which enclose between them the muscular layer also appear in this section the outer plexus being made up of larger vessels than is the inner plexus Small capillary vessels can be seen here and there extending between the venous plexus in the wall of the bronchiolus and the capillary network in the

walls of the alveoli which are in contact with the bronchiolus The capillaries in the alveolar walls are derived from the pulmonary artery, and not from the bronchial artery

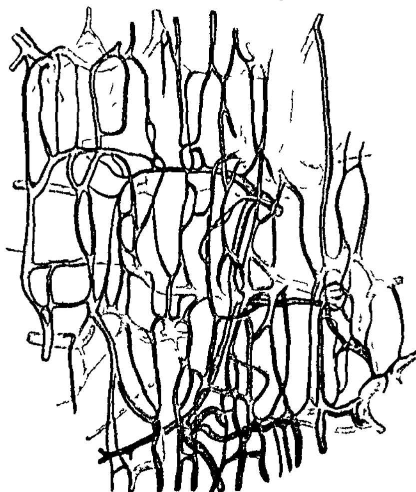


FIG 67—Capillary network within the walls of a bronchiolus Bronchial artery red, capillaries dark blue venous plexus on the inner surface of the muscular layer light blue ×100

In Figure 66 a portion of a bronchiolus, which has been cut open longitudinally, has been dissected in such a manner that the left leaf of the dissection is made up of the fibrous coat, while the right leaf is composed of the muscular layer, the *tunica propria* and the epithelium The two leaves were then so placed that they could be opened like the leaves of a book One of them was turned to the left while the other was turned to the right, by this proce

dure the left leaf lay with its outermost surface down and the right leaf with its epithelial surface down

The left leaf shows a portion of the arterial plexus, some of the smaller arterial branches, a portion of the outer venous plexus, and one of the venous radicles which would have eventually taken part in the formation of a pulmonary vein (see Fig 69)

The right leaf has a number of points of interest A little to the left, and somewhat below its center, a branch of the bronchial artery can be seen, situated underneath the point where three venous twigs apparently come together The artery and the venous twigs were cut off from the arterial and venous stubs which can be recognized nearly opposite to them, on the left leaf The larger venules are part of the plexus outside the muscular layer, the smaller venules, which, with the fine straight vessels, form the rectangular areas, belong to the venous plexus which is situated inside the muscular layer, while the fine straight vessels are the capillaries which are situated just beneath the epithelium in the *tunica propria* It is necessary that the artery and its course in each leaf be recognized, for this is the artery that appears in Figure 60, and gives origin to the capillary network there shown

Figure 67 is an enlarged view of the lower half of the right leaf in Figure 66 This was obtained by turning the leaf over, so that its epithelial surface came to lie uppermost for this reason the course of the artery appears to be reversed from that which it takes in Figure 66 The dark blue vessels are the superficial capillaries, the lighter colored vessels are situated deeper, and take part in forming the venous plexus on the inner side of the muscular layer

The artery is seen breaking up into a number of branches which at first run parallel to the muscle bands, they then give rise to a number of short branches, which terminate in capillaries that run lengthwise within the *tunica propria* of the bronchiolus

and the air spaces beyond them are supplied by the pulmonary artery and not by the bronchial artery LeFort, Kuttner, Schwarz and others have previously stated and my own investigations confirm their observations

As the *bronchioli respiratorii* are approached the bronchial arteries terminate in a network of elongated capillaries which represent the capillaries in the *tunica propria* and the attenuated venules outside the muscular layer By this arrangement the muscular layer is still enclosed by a vascular network The capillary network thus formed quickly merges with the capillary network in the walls

of the alveoli, and from *this point onward the* pulmonary artery alone supplies the bronchial tree

Figure 68 *shows a bronchiolus* respiratorius which is dividing on the right, into two ductuli alveolares The section was of sufficient *thickness to include the full* diameter of the bronchiolus In order to understand this section completely it is necessary to recall *certain structural* features of a bronchiolus respiratorius the muscle is arranged in the form of anastomosing bands, opening out of the bronchiolus, through the mesh formed by these anastomosing bands, are the alveoli, the alveoli are supplied with blood by the pulmonary artery, and they take part in respiration (Fig 61)



Fig 68 —Vascular supply of a bronchiolus respiratorius For a description see text Pulmonary artery, red, all other vessels, blue ×68

The plane of the upper surface of the section in Figure 68 is such that the muscle bands are intact, while the alveoli have been cut off close to their connection with the bronchiolus That this is the case is shown by the clear openings leading into the bronchiolus A branch of the pulmonary artery which was dividing into three smaller branches was cut through just as it arched over the rounded contour of the bronchiolus If the capillaries which are directly connected with that portion of the artery which lies above the muscle in the center of the section be followed, it will be found that some of them pass beneath the bands of muscle while others pass outside of the muscle, in this manner continuing the relation of muscle and blood vessels which has existed throughout the bronchial tree

The capillary network which is in close apposition to any division of the air tubes or to any blood vessel is always coarser than in the walls of the air spaces This is shown along the upper border of Figure 63 where the capillaries are uniting to form a small venous radicle

It is interesting to note that this transitional zone from the bronchial to the pulmonary circulation in the bronchial tree is a favorite place for tubercles to develop I have found this true not

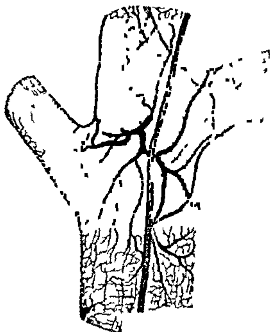


Fig 69 —A branch of the pulmonary vein arising from the place where branches are given off from a main bronchiolus Bronchial artery red pulmonary vessels blue ×50

only in experimental tuberculosis but also in early human tuberculosis Whether this be due to a retardation of the circulation at

at the hilum of the lung these arise from the first or the first two dividing points of the bronchial tree they may also receive branches from that part of the pleura which is in close proximity to the hilum These bronchial veins empty into the azygos the hemiazygos or one of the intercostal veins

Within the lung the radicles which have their origin from the outer venous plexus in the walls of the bronchi and bronchioli or from the capillary network in the walls of the bronchioli re pi ratorii unite at the place where the bronchi or bronchioli divide to form a radicle of the pulmonary vein

In Figure 69 a branch of the pulmonary vein is shown which has its origin from small venules that come from the place where two bronchi which are respectively 3 and 4 mm in diameter arise from a bronchus which is 6 5 mm in diameter Another vein which was formed in like manner was present on the opposite side of the bronchus As a rule two radicles of a pulmonary vein arise from the place where bronchi or bronchioli divide Smaller veins ari e from the distal end of ductuli alveolares these are also paired and they join larger branches of the pulmonary vein which are situated on the periphery of a primary lobule To recapitulate except for a limited area about the hilum all the blood which is distributed to the bronchial tree is returned by the pulmonary veins

When the richness of the capillary network in the bronchial walls is considered it can readily be understood that it may be the source of a severe hemorrhage arising either from a localized infection or from a foreign body finding lodgment in an air passage it also as sists in understanding how a localized infection in the wall of a bronchus or a bronchiolus may find its way through the epithelium and gain entrance either into the vascular network in their walls *or into a lymphatic and thus give rise to a hematogenous or to a* lymphogenous extension of the infection

Yates found from his extensive experiences in World War I that wounds of the lung which involve the bronchial artery are much more fatal than those which involve the pulmonary artery this is due to the higher pressure in the bronchial artery which causes splenization or hemorrhagic infarction extending to the pleu ral surface and is almost constantly provocative of empyema Ob struction of the bronchial artery may occasion infarction and gan grene

Do anastomoses exist between the bronchial artery and the pul monary artery? Following the announcement by Ruysch of the

lung the presence of bronchial veins and the relation of the bron chial to the pulmonary blood vessels

Notable contributions have been made to these problems by Wohlfahrt Heller Reisseisen v Sommering Guillot Luschka LeFort Kuttner Zuckerkandl Nakamura and others whose work will be discussed later

Up to the time of Guillot there was a general agreement that the bronchial artery anastomosed with the pulmonary artery Guillot injected the pulmonary artery with a solution of gelatin colored

that the two systems anastomosed but in every instance communications existed between the bronchial artery and the pulmonary vein

Wishing to determine for myself whether there were anastomoses between the two arterial systems I made a series of five sets of injections using the lungs of dogs weighing from 20 to 21 kilos In each injection except the last an 8% solution of Berlin blue in gelatin was used and a pressure of 110 mm of Hg

(1) Berlin blue in pulmonary artery pulmonary vein open Result bronchial blood vessels uninjected

(2) Berlin blue in pulmonary vein pulmonary artery open Result slight injection of bronchial vessels

(3) Berlin blue in pulmonary artery pulmonary vein clamped Result imperfect injection of bronchial vessels

(4) Berlin blue in pulmonary vein pulmonary artery clamped Result complete injection of bronchial vessels

(5) Berlin blue in pulmonary vein until it flowed freely from the pulmonary artery The pulmonary vein was then clamped and a solution of gelatin containing vermilion granules in suspension was forced into the pulmonary artery Result bronchial blood vessels and pulmonary veins blue pulmonary artery red no anastomosis between the two arterial systems

These experiments demonstrated quite conclusively that the bronchial blood vessels are directly connected with the pulmonary vein and can be only partially injected from the pulmonary artery when the pulmonary vein is clamped and then by a backward flow along the venous radicles which arise from the bronchi

From the experimental side confirmation of the above conclusion is found in the work of Ghoreyeb and Karsner Karsner and Ash Berry and Daly and Daly

Do anastomoses exist between the bronchial and pulmonary arteries? If the question be restricted to the arteries it must be answered in the negative If the question be asked if there be anastomoses between the bronchial and pulmonary circulatory systems I answer in the affirmative but it is by means of the capillaries

Throughout the entire bronchial tree capillary anastomoses like those seen in Figure 65 are found It is conceivable that at times the same thing may occur in the lung as elsewhere in the body

namely through some obstruction to the normal flow of blood a vessel or vessels may be developed to a greater degree than is the usual case and in this manner an occasional anastomosis may arise

Another source of misinterpretation is found in the fact that the vasa vasorum of the pulmonary artery are derived from bronchial arteries A branch of the bronchial artery is traced into the wall of a pulmonary artery therefore they anastomose

CHAPTER VI

THE LYMPHATICS

The lymphatics form a closed system of vessels *They do not communicate with the connective tissue spaces neither do they communicate with the pleural cavity by means of stomata*

Lymphatics not only play an important part in the dissemination of disease processes within the lung, but they also assist in the healing of disease processes An example of the former is found in tuberculosis of the latter in pneumonia

Structure of the Lymphatics The larger lymphatics resemble the veins in structure but they differ from them in that their diameter varies greatly within short distances becoming suddenly narrow only to widen immediately Three distinct walls can be distinguished a tunica intima a tunica media and a tunica adventitia The tunica adventitia is the most characteristic coat of the lymphatics since it contains numerous smooth muscle fibers some of which run longitudinally others obliquel The intima consists of a layer of endothelium The smaller lymphatics have only two coats a tunica adventitia which consists of fibro elastic tissue and a tunica intima formed of endothelium The so called lymph capillaries consist of a single layer of endothelium

The lymphatics in the neighborhood of the hilum and in the pleura contain numerous valves while within the lung only an occasional valve is found The valves are usually arranged in pairs they are formed by semilunar folds of the intima and strengthened by a small amount of connective tissue They are covered by endothelium the cells on the side of the valve turned toward the lymph flow are elongated in the direction of the flow while on the opposite side of the valve they are placed transversely across the valve In the lymphatics of the pleura in the septa adjacent to the pleura and at the hilum the valves frequently have a small pouch or sinus where they leave the wall of the lymphatic These sinuses are best demonstrated in longitudinal sections of the valve

In one instance a valve was found which consisted of a single leaf the other leaf being formed by the attenuated wall of the lymphatic into which it opened (Fig 70) Not infrequently valves are seen in cross section sometimes close to their origin from the wall of the lymphatic then again more or less toward their highest point in the vessel (Fig 71)

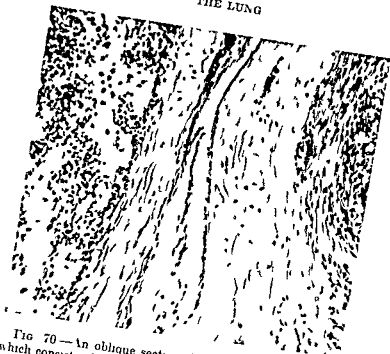


FIG 70 — An oblique section through a lymphatic valve which consists of one leaf the other being formed by the attenuated wall of the lymphatic into which it opens ×150

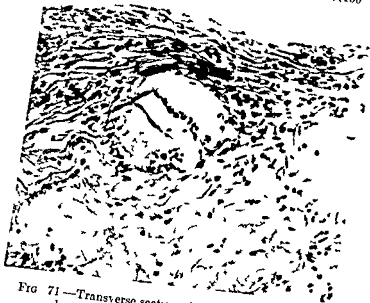


FIG 71 —Transverse section of a valve situated in a lymphatic in the human pleura ×200

nalis the latter accompanies the bronchi the pulmonary artery and its ramifications and the pulmonary veins It also forms a dense network in the connective tissue septa between the secondary lobules The two sets of lymphatics are in communication with

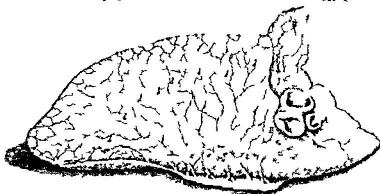


FIG ?—Lymphatics of the lung as illustrated by T Willis

each other in the pleura and at the hilum of the lung The nature of this communication will be discussed later

The lymphatics of the lung were first seen and described by Olof Rudbeck in 1653 He saw them in the pleura of the dog s lung apparently only a few of the main trunks at the hilum of the lung were seen Thomas Willis in his *Pharmaceutice Rationalis* published in 1675 after describing the blood and air vessels of the lung says in regard to the lymphatics

contain not long what is deposited in them therefore there is need of lymph ducts as so many channels whereby the superfluous humour might continually be sent off If these at any time happen to be obstructed or

broken there often follows a Dropsie of the Lungs or Breast and sometimes Coughs and Phthisicks

By preventing the discharge of the contents of the thoracic duct into the subclavian vein in a dog that had eaten and drunk largely Willis caused the superficial lymphatics of the lung to fill and become very apparent due to the fact that they were unable to empty themselves (Fig 72)

Passing over an interval of one hundred years we come to the epoch making work of Cruikshank and of Mascagni on the lymphatics Each of these authors described a superficial and a deep set of pulmonary lymphatics which communicated with each other Both confine their descriptions almost *wholly to the superficial set saying but little about the deep set*

Another interval of nearly one hundred years must be passed over before noteworthy contributions were made to our knowledge of the pulmonary lymphatics though much had been added to our knowledge of the *general distribution of lymphatics in other situations* Wywodzoff studied the lymphatics of the lung of the dog [illegible] from

se

o

described lymph spaces in the walls of the sacculi alveolares in which the lymph collected (These appearances were evidently caused by extravasations and were artifacts) *The larger lymphatics were situated in the walls of the blood vessels and bronchi These two sets of lymphatics communicated with each other* The superficial lymphatics formed a network which was destitute of *valves while the deeper set possessed valves (sic)* The two sets of lymphatics (superficial and deep) were *connected with each other* by branches *which followed the course of the pulmonary* vein from the pleura into the interior of the lung where they joined other lymphatics coming from the bronchi or from other blood vessels [illegible]

epithelial cells lining the bronchi These unit[illegible]
of vessels which in turn gave origin to the *main lymphatic* trunks which passed out of the lung at the hilum *In a second paper he made no reference to his previous statements* and evidently abandoned them The pleural lymphatics eventually formed trunks *which passed to the hilum of the lung*

Sappey states that the lymphatics in the pleura and in the lung communicate freely with each other So free is this communication that one set of vessels cannot be injected without injecting the

other He makes a notable contribution to our knowledge of the pulmonary lymphatics when he describes the secondary lobules which are so plainly marked out in the lung of the ox and in the lung of man as being surrounded by a network of lymphatics which resembles the network of blood capillaries in that it is common to adjacent secondary lobules The superficial (pleural) lymphatics are arranged in the form of irregular polyhedral rings with four five or six unequal sides These vessels have an unusually large diameter

veins are not accompanied by lymphatics but have perivascular lymph spaces about them Klein was a strong advocate of the now obsolete theory of the communication of the pleural cavity with the lymphatics of the pleura by means of stomata situated in the mesothelium of the pleura pulmonalis

In 1900 I published in the *Archiv fur Anatomie und Physiologie* the results of my investigations on the blood vessels and lymphatics using the dog s lung as the basis for my work and in 1908 I demonstrated at the Chicago meeting of the American Association of Anatomists the lymphatics of the human lung

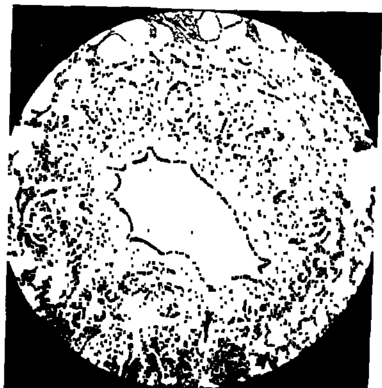
In the early stages of the development of the lungs the bronchi arteries and veins are closely associated with each other As development progresses the bronchi and arteries maintain this close

on the networks of lymphatics which are associated with these structures

Cunningham states that while at first the bronchi and arteries have a common plexus of lymphatics eventually this plexus of lymphatics becomes differentiated into two parts one of which follows the bronchus while the other follows the artery These two plexuses never become entirely distinct but maintain connecting vessels especially at the points where division of the bronchi occurs

Lymphatics of the Bronchi In the larger bronchi which possess distinct cartilages two sets of lymphatics are present They are so arranged that they enclose the cartilages and are connected with each other by anastomosing vessels which pass between the cartilages The smaller bronchi and the subsequent divisions of the bronchial tree have only a single plexus of lymphatics This

plexus becomes more and more reduced in size and complexity until it finally terminates at the distal end of the ductuli alveolares in two small vessels, which join the lymphatics that accompany the radicles of the pulmonary veins which originate at this point. Beyond the ductuli alveolares I have not found any lym-



[illegible] Bunting) ×50

phatics, in other words, no lymphatics are present in the walls of the air spaces distal to the ductuli alveolares

Lymphatics of the Pulmonary Artery. The branches of the pulmonary artery are accompanied by two or three main lymph trunks which are so arranged that one of them lies between the artery and its accompanying bronchus. These main trunks are connected by numerous loops and there is thus formed a network

with a very irregular mesh (Fig 74) At times it seems as though the trunk situated between the artery and bronchus is common to the plexus about each (Fig 74*) The smaller divisions of the artery are frequently accompanied by only a single lymphatic The bronchial lymphatics and the arterial lymphatics are in communication with each other at the place where division of the bronchi



FIG 74 —Reconstruction of the apex of the right lung from a man 30 years old showing branches of the pulmonary artery (red) of the pulmonary vein (blue) and the lymphatics (yellow) The air spaces are bluish grey *Note* the plexus of lymphatics about the large branch of the pulmonary artery If the reconstruction had been commenced a few sections earlier the artery would have been commenced a few sections earlier the artery would have been com

occurs and at the distal end of the ductuli alveolares although as stated above communications may occur in other situations

Lymphatics of the Pulmonary Veins The pulmonary artery enters the lung at the hilum the pulmonary veins emerge from *the lung at the hilum We must therefore trace the lymphatics* from the points of origin of the pulmonary veins As has been pointed out in Chapter V the pulmonary veins arise from the pleura from the walls of the sacculi alveolares from the distal end of the ductuli alveolares and from the place where bronchi

divide Lymphatics are associated with the veins *from all of these* points of origin except those veins which arise from the walls of the sacculi alveolares Since no lymphatics are present in the walls of the sacculi alveolares, there are *no* lymphatics *along* the veins which arise from their walls The smaller veins are *accompanied* by one or two lymphatics but as the veins increase in size there *is gradually formed* a network of lymphatics which has a corresponding increase in complexity (Fig 75) This *is especially true of* those veins which are situated in the connective tissue septa (Fig 75a) As will be seen later, the network of lymphatics about the



veins in this situation has still further connections The lymphatics *which accompany the venous radicles which arise from the* bronchial tree join the lymphatics of the bronchi Those lymphatics which accompany the venous radicles which arise from the pleura *join the plexus of lymphatics in the pleura.* At the place where the venous lymphatics join the pleural lymphatics, valves are present but throughout the lungs the lymphatics are, as a rule destitute of valves (See also page 89)

Lymphatics of the Pleura Sappey described the pleural lymphatics as being arranged in the form of *irregular polyhedral rings*

having four or more unequal sides. My own study of injected and uninjected lymphatics of the pleura confirms this statement (Fig. 76). There is only a single plexus of lymphatics in the pleura,



struction

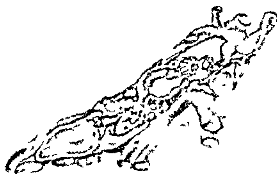


FIG 75a —Plexus of lymphatics about a pulmonary vein This particular vein was situated in an interlobular septum ×20

though a pleural and a subpleural plexus have been described The latter however do not exist The large *lymphatics which take part in* the formation of the irregular polyhedral rings mark out the secondary lobules Within these larger areas smaller areas can be recognized which are marked out by lymphatics of lesser size These smaller areas correspond to the primary lobules *Often still* smaller *lymphatics can be seen situated within the smaller areas* and frequently a fringe of irregular finger like projections is found along the smaller lymphatics Some of these are undoubtedly due to incomplete injection of the lymphatics while others seem to be blind points of origin That they are not occasioned by rupture of the walls of the lymphatics is shown by their having a distinct boundary wall Valves are very abundant but as stated by Cruikshank the lymphatics of the pleura communicate so freely with each other that they readily fill with the injection mass On the other hand valves prevent the passage of any injection mass into the deep lymphatics of the lung The pleural lymphatics unite and form a variable number of trunks which drain into the lymph nodes at the hilum

Cunningham in his study of the development of the lymphatics of the lung in the pig has described lymphatics which come from the pleura covering the diaphragmatic surface of the inferior lobes and drain through vessels situated in the ligamentum pulmonale *into abdominal preaortic lymph nodes and thence to the thoracic* duct while the lymphatics coming from the anterior portion of the inferior lobes drain into the group in lymph nodes at the hilum and thence to the thorac [illegible] regard to the lymphatics pas [illegible] *be true for the pig* [illegible] lymphatics of the pleura have been described by every investigator who has studied the lymphatics of the lung there has been much confusion in regard to their relationship to the deep lymphatics of the lung This has been due in a large measure to the fact that no distinction has been made between lungs which have a thick pleura with well marked connective tissue septa and those which have a thin pleura with no connective tissue septa Then again no distinction has been made between primary lobules and secondary lobules

Lymphatics of the *Interlobular* Septa Sappey was the first to describe these lymphatics with any degree of accuracy and although [illegible] mentions them he does not give any detailed descrip [illegible] of the [illegible] *these septa* Cunningham says He [illegible] description of the interlobular vessels but does not claim to have

found these same vessels" At that time (1902) I described the lymphatics as found in the dog's lung As this animal has a thin pleura and consequently no interlobular septa I could not describe that which did not exist On the other hand I did describe homologous vessels *about the veins on the periphery of the primary lobules* and as

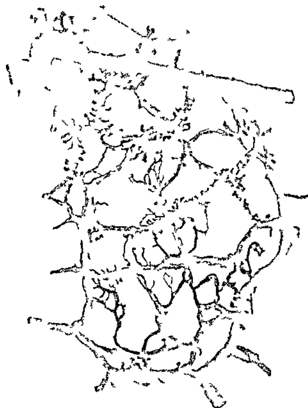


FIG 76 —Lymphatic plexus in the pleura A detailed description of this figure is given in the text ×8

the secondary lobules are made up of primary lobules the inference is that they would be found about corresponding veins on the periphery of the secondary lobules After studying the lymphatics of the human lung I demonstrated these special lymphatics at the meeting of the Association of American Anatomists in 1908 and showed that they were associated with the pulmonary vein and that there was a rich network of lymphatics extending

from the plexus which surrounds the veins into the septa and that *collectively they formed a cordon around the secondary lobules* In an address before the American Roentgen Ray Society in 1916 the year before Cunningham s paper appeared I confirmed the statement of Councilman and gave additional facts Flint also found lymphatics on the periphery of his secondary lobules We have then the presence of lymphatics in the interlobular septa established by the embryological investigations of Flint and of Cunningham and by Sappey s and Councilman s investigations of adult lungs In lungs destitute of interlobular septa they will not be found

In Figure 75a there is illustrated the plexus of lymphatics about *one of the branches of the pulmonary vein which is situated in an* interlobular septum and in Figure 77 a portion of the cordon of lymphatics in an interlobular septum The latter figure shows how the lattice like network of lymphatics extends between a large vein on the left and a smaller vein on the right The small thick



FIG 77 —Plexus of lymphatics in an interlobular septum This illustration is described in detail in the text ×15

walled vessel about midway between the veins is a branch of the bronchial artery

An Enumeration of the Valves Up to the present time I am not aware of a systematic enumeration of the lymphatics within the lung the only paper bearing on the subject with which I am acquainted is that of Kampmeier who made a study of the early development of the lymphatics and their valves in the human lung the main facts of which are contained in the following abstract

In a 2 2 months fetus the lymphatics were just beginning to invade the lung No lymphatics were within the lung or at its periphery

In a 2 5 months fetus the lymphatics have noticeably invaded the lung No valves present.

In a 3 5 months fetus valves were found in the pulmonary lymphatics, especially at the hilum All point towards the hilum No valves were found beyond the area indicated, although at this period the lymphatics have spread themselves throughout the lung and have begun to invade the pleura All the valves point towards the hilum

In a 3 7 months fetus valves were present in the pleura, especially in the *impressio cardiaca* In the septa beneath the pleura the valves point towards the pleura On the lateral surface the majority of the valves point towards the pleura but occasionally a valve was found, especially near

lobe were found

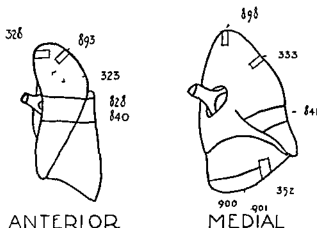


FIG 78 —Diagrammatic outline showing the location of the various blocks used in the following series

In three blocks 1 cm long by 2 mm wide taken from the l

side, and none at the apex were found

Kampmeier's study ended with the new born child In the following tabulation there will be found the results of an enumeration and the location of the valves in such series as I have in the lung of a nine week old child Judging from his Figure 3 Kampmeier used th

not pr

a direc

Series were cut from all parts of the lung Their position and

TABLE I

Series	Location
323	Deep within the upper left lobe No pleura
328	Anterior margin, upper left lobe
333	
352	
828	
840	
841	
893	
898	
900	
901	Costal and diaphragmatic surface, lower lobe

TABLE II

Series Number	Number of Sections	Thickness in Micra	Thickness of Block	Number of Valves
323	60	10	600	1
328	45	10	450	5
333	375	10	3750	53
352	245	10	2450	54
828	200	40	8000	477
840	200	40	8000	181
841	250	40	10000	112
893	278	15	4170	44
898	100	10	1000	8
900	100	40	4000	32
901	50	40	2000	26
Total	1903		44420	993*

TABLE III

In the following tables the location and the number of valves in the various series are given

For the amount of tissue sectioned in each series see Table II

COSTAL PLEURA

Upper Lobe		Lower Lobe	
Series Number	Number Valves	Series Number	Number Valves
328	1	352	17
333	20	828	32
828	15	840	3
840	9	900	18
841	74	901	20
893	29		
898	3		
Total	151	Total	90

TABLE IV
MEDIASTINAL PLEURA

Upper Lobe		Lower Lobe	
Series Number	Number Valves	Series Number	Number Valves
328	1	828	28
333	17	840	2
828	1		
840	3		
Total	22	Total	30

TABLE V
INCISURAL PLEURA

Upper Lobe		Lower Lobe	
Series Number	Number Valves	Series Number	Number Valves
828	47	828	30
840	19	840	6
841	5		
Total	71	Total	36

TABLE VI

Impressio Cardiaca		Diaphragmatic Pleura	
Series Number	Number Valves	Series Number	Number Valves
841	15	352	9
		900	8
		901	2
Total	15	Total	19

TABLE VII

IN SEPTUM TOWARDS COSTAL PLEURA

Upper Lobe		Lower Lobe	
Series Number	Number Valves	Series Number	Number Valves
328	1	352	4
333	6	828	3
828	3	840	1
840	1	900	3
841	8	901	4
893	12		
898	1		
Total	32	Total	15

TABLE VIII

IN SEPTUM TOWARDS MEDIASTINAL PLEURA

Upper Lobe		Lower Lobe	
Series Number	Number Valves	Series Number	Number Valves
328	1	828	12
333	9		
Total	10	Total	12

TABLE IX

IN SEPTUM TOWARDS INCISURAL PLEURA

Upper Lobe		Lower Lobe	
Series Number	Number Valves	Series Number	Number Valves
828	4	828	4
841	4	840	2
Total	8	Total	6

TABLE X

IN SEPTUM TOWARDS HILUM

Upper Lobe		Lower Lobe	
Series Number	Number Valves	Series Number	Number Valves
828	8	828	13
840	3	840	3
Total	11	Total	16

TABLE XI

IN SEPTUM TOWARDS IMPRESSIO CARDIACA

Series Number	Number Valves
841	3
Total	3

TABLE XII

IN SEPTUM TOWARDS DIAPHRAGMATIC PLEURA

Series Number	Number Valves
352	12
Total	12

TABLE XIII

NUMBER OF VALVES ABOUT APEX

This table includes pleura and septa only

Series Number	Number of Sections	Thickness of Sections	Number of Valves
328	45	10	4
893	278	15	41
898	100	10	4
		Total	49

TABLE XIV

IN LYMPHATICS ABOUT PULMONARY VEIN

Upper Lobe		Lower Lobe	
Series Number	Number Valves	Series Number	Number Valves
323	1	352	11
828	7	828	14
840	2	840	3
893	1		
898	2		
Total	13	Total	28

Table XV

In Lymphatics about Pulmonary Artery

Upper Lobe		Lower Lobe	
Series Number	Number Valves	Series Number	Number Valves
828	12	352	1
840	6	828	12
893	2	840	3
898	2	900	3
900	1		
Total	23	Total	19

Table XVI

In Lymphatics about Bronchus

Upper Lobe		Lower Lobe	
Series Number	Number Valves	Series Number	Number Valves
333	1	828	34
828	27	840	14
840	12		
841	1		
Total	41	Total	48

Table XVII

In Septum towards Bronchus

Upper Lobe		Lower Lobe	
Series Number	Number Valves	Series Number	Number Valves
840	1	828	1
Total	1	Total	1

Table XVIII

In Septum towards Pulmonary Vein

Upper Lobe		Lower Lobe	
Series Number	Number Valves	Series Number	Number Valves
328	1	828	2
828	1	840	1
840	1		
Total	3	Total	3

TABLE XIX

IN LYMPHATIC BETWEEN PULMONARY ARTERY AND BRONCHUS

Upper Lobe		Lower Lobe	
Series Number	Number Valves	Series Number	Number Valves
828	4	828	5
840	1	840	3
841	2		
Total	7	Total	8

TABLE XX

IN MEDIASTINAL CONNECTIVE TISSUE

Series Number	Number Valves
828	152
840	79
Total	231

TABLE XXI

IN CAPSULE OF LYMPH NODE

Series Number	Number Valves
828	6
840	2
Total	8

TABLE XXII

DISTRIBUTION AND NUMBER OF SECTIONS

Upper Lobe	1508
Lower Lobe	795
Upper Lobe-incisura	450
Lower Lobe incisura	200
Upper Lobe mediastinum	22
Lower Lobe-mediastinum	30

TABLE XXIII

NUMBER OF VALVES IN VARIOUS DIVISIONS OF PLEURA

Costal	241
Mediastinal	52
Diaphragmatic	19
Incisura interlobaris	107
Impressio cardiaca	15

TABLE XXIV

PLEURAL DISTRIBUTION OF THE VALVES IN THE LOBES

Upper costal	151
Lower costal	90
Upper incisural	71
Lower incisural	36
Upper mediastinal	27
Lower mediastinal	30
Upper impressio cardiaca	15
Lower diaphragmatic	19

TABLE XXV

TOTAL NUMBER OF VALVES IN THE LOBES

Upper lobe	411
Lower lobe	343

If the pleura covering the impressio cardiaca be considered as it is by some as mediastinal pleura then there must be added to the 74 valves already enumerated as being present in the pleura and adjacent septa belonging to the mediastinal pleura the 34 valves in the pleura (Table VI) and the 3 valves in the septa (Table X) classified as belonging to the impressio cardiaca making in all 111 valves in the mediastinal pleura and the septa connected with it

As this volume deals exclusively with the lung the terms costal diaphragmatic and mediastinal describe various relations of the *pulmonary* pleura and not that lining the thoracic cage

Mediastinal connective tissue—what is meant by the term?

Below the hilum of the lung the two layers of the pleura which invest it approach each other and extend downward and backward as a distinct fold forming the *ligamentum pulmonale* This fold extends between the lung the pericardium esophagus and aorta Between the two layers of the pleura bands of collagenous fibers reticulum and elastic fibers are found It is this layer of connective tissue situated between the folds of the pleura and covering with a thick layer the adjacent lobes of the lung that I have designate

Anatomical

tum pulmonale

logical structure is contained in a few lines by W Schulze

The term mediastinal connective tissue is not altogether satisfactory but I shall continue its use until a better one is found

present throughout the lung and pleura and more valves are present It is not however possible to make a direct comparison on account of the difference in the materials used In only two instances can anything comparable to a comparison be made at the apex of the lung and in the diaphragmatic region



Fig 79 —Transverse section through the ligamentum pulmonale from the lung of a child two months old Included in the section are the esophagus and the upper and lower right lobes of the lung ×15

According to Fishberg Tendeloo states that there is a defective lymph circulation at the apex of the lung and Bartels says there is a well known defective development of the pulmonary lymphatic system at the apex of the lung These statements do not coincide with my own studies as shown in various reconstructions from the

Series 328 893 and 898 were cut from this region The location of these is given in Table I and is indicated in the outline sketch (Fig 78) The number of sections the thickness of the blocks and the number of valves is given in Table II The blocks used by Kampmeier measured 10 mm from side to side and 2 mm in thickness



Fig 80 —Reconstruction of lymphatics in the pleura in which the course of the lymph flow is indicated by a series of arrows placed directly over the valves ×33



Fig 81 —Same reconstruction as Figure 80 with the surface removed over two of the valves showing the direction in which they point and thus indicating the direction of the lymph flow ×33

Series 328 measured 6.5 mm from side to side and was 450μ thick, although it was a short series and less than one-fourth the thickness of Kampmeier's block, it contained 4 valves in the pleura and septa. Series 893 was cut at the same thickness and from approximately the same region in the left lung as the block used by Kampmeier from the right lung, but, while his block was 2 mm thick



FIG 82.—Semi-diagrammatic tracing of the lymphatics at the apex of the reconstruction shown in Fig 75. Pulmonary vein in solid black. L^1, L^2 lymphatics. L^1 runs lengthwise along the apex. L^2 extends across the apex of the lung from the costal to the mediastinal surface. 1, 2 and 3 indicate the various positions in which valves may be found. Full description in the text.

the thickness of the block used for Series 593 was 4.17 mm and contained 41 valves in the pleura and septa, while Kampmeier found no valves in his series. Block 898, also cut at 10μ, was one millimeter in thickness and contained four valves in the pleura and septa.

Kampmeier found 13 valves in a block of tissue 2 mm thick, adjacent to the diaphragm, in a new born child. From Table II we found that, in the nine week-old child, the thickness of the



FIG 83—Section through the lymphatics at the hilum of the lung At the upper right of the photograph a section of the pulmonary vein At the lower left corner a fragment of a bronchus with a small plate of cartilage Note the position of the valves in the two lymphatics In both instances they point towards the hilum The smaller lymphatic which is situated between the pulmonary vein and the parenchyma of the lung at a higher level joined the larger lymphatic which is situated between the pulmonary vein and the bronchus ×100

blocks which include the diaphragmatic pleura Series 352 900 901 amounts to 8 45 mm the number of the sections is 395 Series 352 was cut at 10μ but Series 900 and 901 were cut at 40μ Table VI gives the total number of valves in the diaphragmatic pleura as 19 and Table XII the number of valves in the septa towards the diaphragmatic pleura as 12 this makes the total number of valves found in the diaphragmatic region corresponding

loser be l by Kamp

to 8 45 mm in other words in the combined block of tissue four times as thick as that used by Kampmeier there were proportionately fewer valves

pointi g

an exceedingly doubtful case The illustration gives the impression of a section through a lymphatic which as is often the case is dividing into two branches as it approaches the pleura Still a study of the serial sections might show that after all it was a valve

I found several valves which apparently pointed inward but by following out the serial sections it was found that the lymphatic joined another a few sections further on and the lymph flow was not into the lung In one instance a reconstruction was made in order to make clear the course of the lymphatic Figure 80 is a photograph of the reconstruction in which the course of the lymph flow is indicated by arrows placed directly over the valves and pointing in the direction of the lymph flow



Fig 84 —Section tl rougl a septum between two secondary lobules Transverse section of branches of tl e pulmonary vein can be seen situated along the course of the septum At the r ght of the section of the more deeply s tuated pulmonary vein a section of a valve situated in the wi lely dilated lymphatic can be seen It points (opens) outward that is toward the pleura Tl is valve is sit ated 1 8 mm eneatl the inner n argin of the leura ×40

of its sharp borders be studied it will l e found that at just such a point as Kampmeier figures a

valve, a septum extends from one surface of the lung to the other and that a lymphatic extends along this septum, joining the two pleural networks of lymphatics with each other

In a lymphatic passing through a septum of this type, a valve may occupy one of three positions It may be close to the costal surface and apparently point inward, it may be on the opposite side near the junction of the two lymphatics and point away from the costal surface, it may be in the lymphatic of the opposite side



FIG 85 —Section showing the presence of a valve at the point where a lymphatic situated in a septum joins one situated within the pleura The valve points (opens) towards the pleura Further on at the left another valve can be seen situated within the pleural lymphatic ×100

and point towards the hilum, the connecting lymphatic containing no valve Whatever the position of the valve, the flow is through the lymphatic from the costal side towards the opposite side and on towards the hilum (Fig 82)

Kampmeier has shown that there is a gradual extension of the lymphatics into the lung from 2 2 months of fetal life to the new-born child, and that there is a proportional increase in the number of valves It is not improbable that in the nine-week old child new valves have developed coincident with the increased functional activity of the lung, for example, at the apex of the lung

and that expansion of the lung may account for the differences, for example, in the diaphragmatic pleura.

Direction of the Lymph Flow. The direction of the lymph flow is a matter of very real importance to the physiologist, to the clinician and to the worker in experimental medicine. It is not possible at the present time to describe the lymph circulation in the lung as definitely as the blood circulation



FIG 86—A valve situated at the entrance of a lymphatic in a septum into one in the pleura The valve opens (points) towards the pleura Human lung ×100

In the early stages of the development of the lymphatics of the

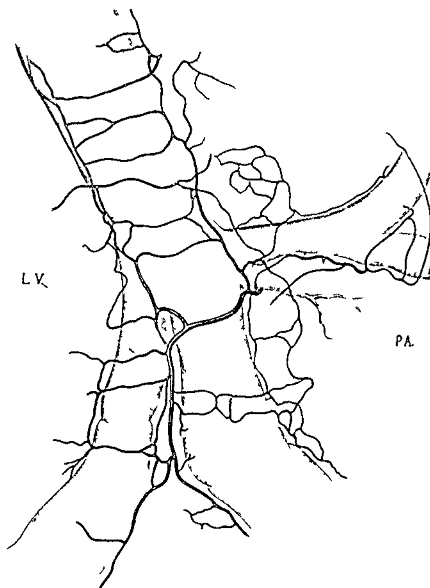


Fig 87 —From a section taken parallel to and including the pleura of the lung of a dog Thickness of section 100 micra The lymph vessels are fully distended L V lymph vessel P A pulmonary artery situated beneath the pleura A radicle can be seen arising from the artery and giving origin to the network of vessels about the lymphatics ×50

true function of valves however, as expounded by Harvey, remains unshaken There is no ebb and flow of the lymph as stated by Tendeloo any more than there is an ebb and flow of the blood

Which way do the valves in the lymphatics of the lung point, or open what purpose do they serve and how do they indicate the course of lymph flow within the lung?

Apparently the flow in the bronchial and arterial lymphatics is towards the interior of the lung for there is a constant drainage of lymph from their combined network by the lymphatics which arise from it and pass along the venous radicles which arise at the point where the bronchi divide and from the distal end of the ductuli alveolares Beyond the ductuli alveolares no lymphatics are found In other words *no lymphatics are present in the walls of the atria or sacculi alveolares*

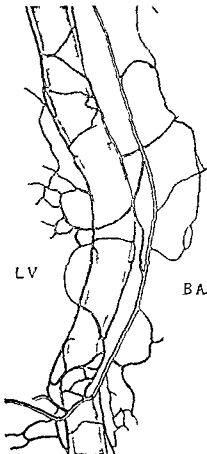


Fig 83 —A lymphatic and its accompanying lymph vessel X50

The lymphatics which accompany the pulmonary vein and its branches except in the narrow zone described below, drain within the lung towards the hilum and are provided with valves which point (open) inward toward the hilum showing that the lymph flow is from within and centralward (Fig 83)

Along a narrow zone situated just beneath the pleura which averages between two and three millimeters in depth the lymphatics situated in the septa arising from the pleura and marking out the secondary lobules are provided with valves which point (open) outward that is toward the pleura (Fig 84)

The only communication between the superficial (pleural) lymphatics and the deep (pulmonary) lymphatics takes place at this point but the presence in the pulmonary lymphatics of valves which point towards the pleura precludes the flow in the pleural lymphatics from entering the lung (Figs 85 86)

The lymphatics form a very abundant network within the pleura they are provided *with valves which open in all directions* This allows free circulation of the lymph within the limits of the pleura The direction of the flow at the sharp borders of the lung has already been described

The pleural lymphatics eventually unite to form main trunks which together with the lymphatics coming from the interior of the lung along the pulmonary veins enter the tracheobronchial lymph nodes

Attention has already been called to the distinction between lungs with a *thin* pleura and those with a *thick* pleura, also to the difference in the blood supply to the pleura In the dog which has a thin pleura it is the *pulmonary artery* that supplies the pleura while in man with a thick pleura it is the *bronchial artery* that supplies the pleura

The presence of a network of blood vessels about the pleural lymphatics has been overlooked by nearly all the investigators Sappey and Dogiel seem to be the only modern investigators who have previously recognized that the pleural lymphatics are surrounded by a network of blood vessels

In the dog this network is derived from the pulmonary artery (Fig 87) while in man it is derived from the bronchial artery (Fig 88)

CHAPTER VII

PULMONARY LYMPHOID TISSUE

The distribution of lymphoid tissue within the lung the situations in which it is to be sought and the relation which it bears to the air passages the blood vessels the lymph vessels and the pleura have been passed over lightly in general descriptions of the histology of the lung

processes may be conveyed An example of such conveyance is shown in Figure 89 This is a reconstruction from a case of tuber
ılar pleura
which car
ercle which
was the source of the infection was situated in front of the angle
for
of
of
tuberculous and *pink* the other lymphatics which enter the node formed a wide open bypath through the node The toxins contained in this bypath and the associated sinuses occasioned an intense hyperplasia of the lymphoid tissue in the remainder of the node (yellow) The yellow lymphatic at the left of the node probably connected with those on the right at some point above the limit of the series of sections The efferent lymphatic which leave the node on the left is *orange*

The presence of lymphoid tissue and even of lymph nodes in the lung was recognized by many of the earlier investigators notably by Burdon Sanderson Ruge Klein Schottelius and Franken

sought and it has a fairly constant relation to the various structures which go to make up the framework of the lung For convenience of description lymphoid tissue may be considered

1 In its relation to the bronchi
2 In its relation to the blood and lymph vessels
3 In its relation to the pleura

Lymphoid Tissue in its Relation to the Bronchi According to Burdon Sanderson, in the guinea pig,

masses of a [illegible]

as the blood vessels are separated from the air cells, while those which



FIG 89—A small lymph node situated in the interlobular pleura with its afferent and efferent lymphatics See text for full description One-fifth the size of the reconstruction

lie near bronchi of sufficient size to be possessed of cartilages, are found to lie in a corresponding position outside of the fibrous layer in which the cartilages are embedded In every instance I have found the adenoid masses occupying a position between the air tube and the nearest artery

Frankenhauser made a careful study of the trachea and bronchi in a number of animals and found in the bronchi of them all including man masses of lymphoid cells, sometimes internal sometimes external to the cartilages Lymph nodes were found in the adventitia of the bronchi usually at the place where branches were given off

Arnold describes subpleural, perivascular and peribronchial masses of lymphoid tissue In the walls of the bronchi of young children he failed to find in the normal lung any masses of lymphoid tissue they were always situated in the peribronchial connective tissue In the walls of the bronchi of the adult he also failed to find any distinct masses of lymphoid tissue

Kolliker found in the walls of the bronchi of man masses of lymphoid tissue which closely resembled lymph follicles Similar

masses were also found in cartilaginous bronchi 2 to 3 mm and less in diameter, and were in all cases situated between the cartilage and the tunica muscularis In non-cartilaginous bronchi Kölliker failed to find any collection of lymphoid cells On the other hand, Stohr and Kolliker, working on the lungs of the dog and rabbit, found small masses of lymphoid tissue in bronchi 0 1 to 0 3 mm

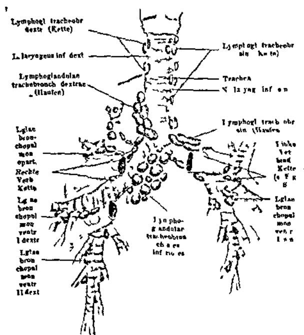


Fig 90 —Distribution of the tracheo bronchial lymph nodes according to Sukiennikow

in diameter which in some cases extended into the mucosa In the human lung Kolliker failed to find any lymphoid tissue in the mucosa Both Verson and Dolkowsky have, however, described numerous small cells in the mucosa situated just beneath the epi-

found, in normal lungs, scattered groups of lymphoid cells which were situated external to the tunica muscularis

Oppel has found lymphoid tissue in the bronchi of representatives of the vertebrate phylum from monotremes to man

Sukiennikow has described and figured the lymph nodes situated along the larger bronchi of the human lung He found them quite

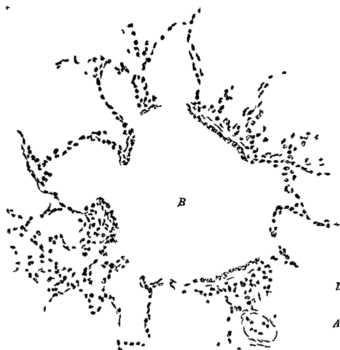


Fig 91 —Transverse section of a bronchiolus respiratorius from the lung of the cat B bronchiolus respiratorius, A artery L, lymphoid tissue situated between the artery and bronchiolus ×200

constant at the place where branches were given off His study did not extend as far as the non-cartilaginous bronchi (Fig 90)

In my own investigations I have used the lungs of man, the cat, dog, rabbit, guinea pig and rat I have found along the larger bronchi not only scattered masses of lymphoid tissue but also lymph follicles and nodes These latter were generally situated at

the place where branches were given off They did not the rat excepted, extend beyond the tunica muscularis

In bronchi which have cartilages in their walls the lymphoid tissue may be situated between the cartilage and the tunica muscularis or outside of the cartilage in the peribronchial connective tissue, or in the space between two adjacent cartilages the position seems to depend on the quantity of lymphoid tissue present

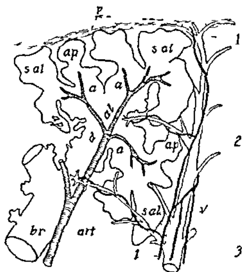


Fig 92 —Schematic longitudinal section of a primary lobule of the lung showing the relation of the blood vessels to the air spaces and to the pleura the position of lymphoid tissue and its relation to the air spaces blood vessels lymphatics and pleura Art pulmonary artery v pulmonary vein l lymphatics The portion of alveolares d al only one of which is carried out in detail a a a three atria each of which communicates with sacculi alveolares s al around the periphery of which are situated the alveoli pulmonum a p p pleura pulmonalis

Klein found, in small bronchi which are devoid of cartilage lymph follicles extending not only close up to the muscular coat but also protruding through this latter into the proper mucosa i e into the layer between the epithelium and the muscularis'

My own results do not support this statement of Klein I have failed to find in *normal* lungs along the bronchioli respiratorii and ductuli alveolares (non-cartilaginous bronchi) of man and of all the animals investigated distinct lymph follicles but have found in each instance small masses of lymphoid tissue which were situated outside the tunica muscularis between it and the accompanying branch of the pulmonary artery Figure 91 shows a section through a bronchiolus respiratorius and exhibits the characteristic appearance of lymphoid tissue in this situation under normal conditions

Lymphoid Tissue in its Relation to the Blood and Lymph Vessels For a complete understanding of the relation of lymphoid tissue to the pulmonary artery and vein, it will be necessary to outline for a second time the distribution of both the blood and *lymph vessels, because lymphoid tissue is intimately associated* with the lymph vessels, and the lymph vessels accompany the blood vessels

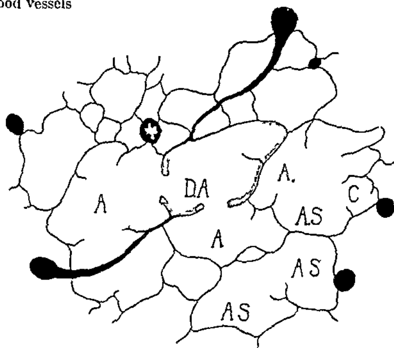


FIG 93 —Combination of three sections taken through the center of a primary lobule of the lung of a dog *D A*, *ductulus alveolaris*, *A A A* atria ... ca muscu ... pulmonary ... nary veins ... alveolaris

sic

central position in the primary lobule ...
has its system of lymph vessels which are in communication at the place where the bronchus divides and at the distal end of the ductulus alveolaris

The branches of the pulmonary vein, on the other hand are situated on the periphery of the primary lobule *In Figure* 92

only one vein is shown, but there are always several of these veins arranged about the primary lobule as is shown in a transverse section of the lobule (Fig 93)

There is an important exception to the peripheral situation of the pulmonary vein, this is indicated in Figures 92 and 93 These

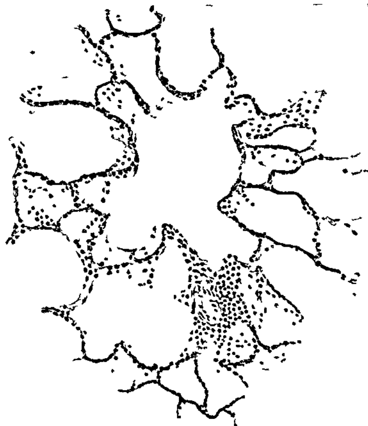


Fig 94 —Transverse section through a ductulus alveolaris from the lung of a cat The small mass of lymphoid tissue is seen lying between the artery and the air spaces The larger air space just above the artery is a portion of an atrium ×200

venous radicles take their origin from the distal end of the ductulus alveolaris and consequently come to lie within the primary lobule There are two of these veins one on either side (Fig 93), and they carry off the last remnant of the blood which is brought to the bronchus by the bronchial artery All along the course of the

bronchi, wherever a branch is given off, venous radicles take their origin These radicles join one of the pulmonary veins (Fig 92) Like those within the primary lobule they serve to carry blood from the bronchial to the pulmonary circulation

The pulmonary veins, like the pulmonary artery, have a system of lymph vessels They are in communication with the bronchial system at the place where the bronchus divides and at the distal end of the ductulus alveolaris where the bronchial system of lymph vessels terminates (Fig 92)



Fig 95 —Section from the lung of a cat showing the junction of one of the small veins taking its origin from the distal end of a ductulus alveolaris (Fig 93) with one of the main branches of the pulmonary vein situated on the periphery of a primary lobule ×400

When lymphoid tissue is present along the course of the pulmonary artery it is situated between the artery and the adjoining air spaces rather than between the artery and bronchus as is the case with bronchial lymphoid tissue The lymphoid tissue may extend for some distance along the artery, but the sheath like arrangement described by some authors is not to be considered a normal arrangement Figure 94 is from a section taken through a ductulus alveolaris and shows lymphoid tissue lying between the artery and the adjoining air spaces which in this instance are portions of atria Only exceptionally have I seen lymph follicles along the course of the arterial lymph vessels In the normal human lung I have failed to find them

The presence of lymphoid tissue along the course of the pulmonary artery has been noted by nearly all who have studied its distribution in the lung, but the presence of lymphoid tissue along the course of the pulmonary veins was not recognized until much later

If one of the small veins which takes its origin from the distal end of a ductulus alveolaris (Fig 93) be followed until it joins one of the small trunks of the pulmonary vein situated at the periph

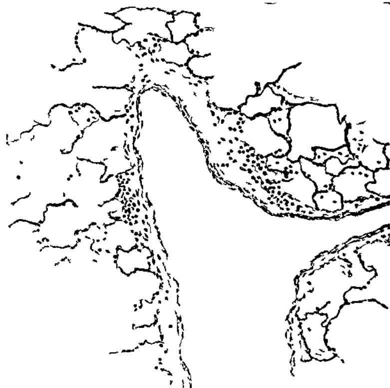


FIG 96 —Section from the lung of a rabbit showing the junction of a vein coming from a bronchus where it divides (see Fig 93) with a main branch of the pulmonary vein In this section there are two small masses of lymphoid tissue one in the angle formed by the smaller vein with one of the main branches of the pulmonary vein and lying close to a lymph vessel the other situated on the opposite side of the vein belongs to a second and larger vein which joins the main branch obliquely ×165

ery of the primary lobule there will usually be found at the place of junction a small mass of lymphoid tissue as is shown in Figure 95 These masses of lymphoid tissue are situated in the adventitia and are associated with the lymph vessels which accompany the veins

Not only do veins arise from the most distal end of a bronchus but they also arise from the place where branches are given off (Fig 93) If we follow one of these branches it will be found that, where it joins one of the main trunks of the pulmonary vein, lymphoid tissue is present in greater or less quantity

In Figure 96, which is taken from the lung of the rabbit, one of these veins is shown entering a large venous trunk The amount of lymphoid tissue is small and in normal lungs may slightly exceed the quantity present in this section As soon as any pathological



FIG 97 —Section of the human lung showing a branch similar to that in Figure 96 joining one of the main branches of the pulmonary vein which, in this instance is situated in a connective tissue septum between two secondary lobules There is a moderate amount of pigment present ×100

process occurs, these small masses frequently become greatly augmented in size

I have failed to find lymphoid tissue present where small venous radicles coming from the walls of the sacculi alveolares join other veins of similar size and origin

In the human lung the same relation between lymphoid tissue and vein exists Figure 97 is taken from a section which shows the

overlooked.

If only individual sections be studied, not infrequently there will be found small masses of lymphoid tissue, apparently unasso-



Fig 98 —Section of the pleura of a child four days old No pigment is present A small mass of lymphoid tissue is seen lying close to the lymph vessel, L In the pleura can be seen a section of a radicle of the pulmonary vein, V, and in the center of the section a small branch of the bronchial artery cut longitudinally ×300

ciated with blood or lymph vessels, situated in the parenchyma of the lung some distance from any bronchus These isolated masses, if they could be followed through a series of sections, would, in nearly every instance, be found to belong to one of the masses of lymphoid tissue associated with the veins; in a few instances I have found such masses to belong to a bronchus situated immediately above or below the plane of the individual section being studied

Lymphoid Tissue in its Relation to the Pleura. The presence of lymphoid tissue in the normal pleura was established by Arnold and since then has been described by Lüders, Heller and other

investigators The amount of lymphoid tissue in the pleura is considerable, but I have failed to find in the *normal* pleura of man or of any animal which I have examined, lymph follicles or nodes

By referring to Figure 92 we see at 1, a pulmonary vein taking its origin from the pleura As is shown in Figure 93, there are several of these veins about the periphery of each primary lobule



Fig 99 —Section of the pleura of a child seven years old A bronchial artery V pulmonary vein L lymph vessel In the center of the section and just to the left of the lymph vessel a mass of lymphoid tissue is seen a second and smaller mass can be seen just beneath the lymph vessel A small amount of pigment is present ×300

At the place where the pleural radicles unite to form a pulmonary vein we usually find a small mass of lymphoid tissue

In the human lung there are connective tissue septa which separate the secondary lobules from each other In these septa blood and lymph vessels are associated with each other and where they join the pleural vessels there is always found a mass of lymphoid tissue

The situation of the lymph follicles and nodes described by Luders corresponds to the situation in which I find lymphoid tissue

have developed from the normal masses of lymphoid tissue This development may arise from the presence of irritating substances as for example, particles of carbon In this case we find more or less pigmentation of the masses of lymphoid tissue and deposition of pigment along the course of the lymph vessels throughout the



Fig 100 —Section taken [illegible]
years old
of the br
vessels I
seen Scattered about in the section are numerous phagocytes ×250

lung In other cases we may have an hyperplasia of the already existing lymphoid tissue as for example in leucemia In these cases absence of pigment is the rule

In Figure 98 we have a section taken through the pleura of a child four days old No pigment is present and this may be taken as representing the amount of lymphoid tissue usually found in any one situation in the normal pleura of man before the deposition of any irritating substance

investigators The amount of lymphoid tissue in the pleura is considerable but I have failed to find in the *normal* pleura of man or of any animal which I have examined, lymph follicles or nodes

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pleura as *normal structures*, they must be pathological and must

have developed from the normal masses of lymphoid tissue This development may arise from the presence of irritating substances as for example particles of carbon In this case we find more or less pigmentation of the masses of lymphoid tissue and deposition of pigment along the course of the lymph vessels throughout the



Fig 100 —Section taken perpendicular to the pleura of a man thirty-eight years old A large amount of pigment is present In the pleura we see sections of the bronchial artery A A of a radicle of the pulmonary vein V of lymph vessels L L Just below the lymph vessels a mass of lymphoid tissue can be seen Scattered about in the section are numerous phagocytes ×250

lung In other cases we may have an hyperplasia of the already existing lymphoid tissue as for example in leucemia In these cases absence of pigment is the rule

In Figure 98 we have a section taken through the pleura of a child four days old No pigment is present and this may be taken as representing the amount of lymphoid tissue usually found in any one situation in the normal pleura of man before the deposition of any irritating substance

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... of the lymph follicles and nodes described by

pleura, as normal structures they ...

Pulmonary Lymphoid Tissue in Old Age Lymphoid tissue in the lung increases from childhood to old age, this increase is largely due to the irritation arising from the constant inhalation of irritating substances

Obtaining material has been more difficult than anticipated, not only because the autopsy material available was limited, but also because there are many chronic affections of the lungs that occasion the rejection of the material due to an increased production [illegible]

bronchitis present in both lungs associated in one of them, with a chronic inflammation of the pleura

No attempt has been made to discuss pneumonokoniosis in individuals who have worked in dust laden atmospheres Every lung studied has been carefully selected

I have accepted Sukiennikow's description of the tracheobronchial and bronchopulmonary lymph nodes Further study has shown that his description of their character and situation agrees in general, with the results which I have obtained from the lungs of adults and of old age However, in those lungs which showed the greatest amount of pigmentation the lymph nodes at the hilum and the bronchopulmonary nodes were increased in size, and were highly pigmented, while in those lungs which were comparatively free from pigment these nodes were not greatly increased in size and showed but slight pigmentation

While Sukiennikow called attention to the greater number of lymph nodes associated with the right lung he did not call attention to the fact that there is a greater number of lymph nodes associated with the eparterial bronchus than with the bronchus which supplies the middle lobe or with that which supplies the lower lobe of the right lung

In the lungs of individuals thirty years old or younger who have died from diseases other than pulmonary, I have rarely found a true lymph node beyond the point where the second ventral branch is given off from the main stem bronchus Beyond this point I have occasionally found a single lymph follicle (germ center) in the angle between the main stem bronchus and the third ventral branch but usually only lymphoid tissue in greater or less quantity is present In lungs from individuals sixty or more years old, there is a small lymph node in the angle formed by the main stem bronchus and the third ventral bronchus and the lymphoid tissue associated with the finer divisions of the bronchial tree is always increased in quantity, in case there is much pigment (carbon)

Figure 99 shows a section taken through the pleura of a child seven years old here we see that the amount of lymphoid tissue has materially increased due no doubt to the presence of the small quantity of pigment

Contrast these sections with Figure 100 which is taken through the pleura of a man thirty eight years old In this section we see a considerable quantity of pigment which is especially abundant about the lymph vessel Scattered aggregations of pigment are present in the lymphoid tissue which is more abundant than in Figure 99 Phagocytes laden with particles of carbon are to be seen in various parts of the section their destination being the lymphoid tissue Sections taken through other portions of the pleura show larger collections of pigment and consequently larger masses of lymphoid tissue *The increased amount of lymphoid tissue is un do*

the

have already referred to this when describing the lymphoid tissue associated with veins

The investigations of Shingu show that in children under twenty three days old no pigmentation of the lung is present from that

quantity of pigment than those of persons living in an atmosphere comparatively free from carbon and my own investigations show a corresponding increase in lymphoid tissue In fact *I am forced to believe that in the lungs contrary to what occurs in the alimentary tract the quantity of lymphoid tissue increases from childhood to old age and that this increase is largely due to the irritation arising from the constant inhaling of irritating substances*

The mode by which particles of carbon are removed from the air spaces and deposited in these masses of lymphoid tissue and along the course of the lymph vessels is of interest When particles of carbon are inhaled it is as a rule only the finer particles that penetrate as far as the alveoli pulmonum Here the particles come in contact with the epithelium covering the walls of the alveoli and may frequently be seen lying free on their surface I have been unable to convince myself that the normal pulmonary epithelium becomes phagocytic on the other hand many phagocytes more or less laden with particle of carbon are present in each alveolus *and the question arises* what is their origin? In spite of many contributions on this subject the question has not been answered in a satisfactory manner

Pulmonary Lymphoid Tissue in Old Age Lymphoid tissue in the lung increases from childhood to old age, this increase is largely due to the irritation arising from the constant inhalation of irritating substances

Obtaining material has been more difficult than anticipated, not only because the autopsy material available was limited, but also because there are many chronic affections of the lungs that occasion the rejection of the material, due to an increased production of lymphocytes For example the lungs from an individual ninety years old appeared, grossly, to be an excellent specimen from extreme old age Sections however, showed that there was a chronic bronchitis present in both lungs, associated, in one of them, with a chronic inflammation of the pleura

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present, it may be so abundant as to obscure the amount of lymphoid tissue

An increase in lymphoid tissue along the finer divisions of the bronchial tree, in individuals over sixty years old, is especially marked at the point where bronchioli divide into *bronchioli respiratorii*, and at the distal end of the *ductuli alveolares* In the latter situation lymphoid tissue is often recognized with difficulty in the lungs of individuals under thirty years of age, in old age, however, it is much more pronounced and the presence of pigment makes it still more distinct

Besides these distinct masses of lymphoid tissue there is present, in old age in the walls of the bronchi and the larger bronchioli, situated between the epithelium and the smooth muscle, a delicate layer of diffused lymphoid tissue

It is often difficult to determine whether a given mass of lymphoid tissue belongs to the bronchus or to the accompanying pulmonary artery Because of this difficulty, an arbitrary classification was made, by which masses of lymphoid tissue lying between the artery and bronchus were considered as belonging to the bronchus, while those masses situated between the artery and the adjoining air spaces were considered as belonging to the artery

In the lungs of individuals of sixty or more years, this distinction does not always hold true, for at times the artery is completely surrounded by lymphoid tissue which fuses with that belonging to the bronchus, thus forming a common mass In the lungs of individuals under thirty years of age it is rare to find a sheath like arrangement of lymphoid tissue extending along the pulmonary artery, in the lungs of old people it is not uncommon I have never seen within the normal lung, at any age, a lymph node or a lymph follicle associated with the pulmonary artery

In old age, when much pigment is present, a thin layer of diffused lymphoid cells may be present along the outer wall of the finer divisions of the pulmonary artery Unless especially looked for, the lymphoid cells may be obscured by the pigment

In all those situations in which lymphoid tissue is found associated with the pulmonary veins it is increased in quantity in old age This is especially true of those masses which are associated with veins which arise from the bronchial tree and join the venous trunks situated in the connective tissue septa which mark out the secondary lobules

Besides these masses of lymphoid tissue which are directly associated with the veins, small collections of lymphoid tissue are scattered throughout the septa which have no direct relationship to radicles of the pulmonary vein These isolated masses are

usually found where alveoli that are in the direct line of the air current abut against the septa

For the first three weeks of life the pleura does not show any pigmentation, and the amount of lymphoid tissue is small, but after that time the pleura shows an increased amount of pigment, and *per consequens*, an increase in the amount of lymphoid tissue

In the pleura of individuals who have lived until old age in an atmosphere in which carbon or other particles of dust are suspended, the lymphoid tissue of the pleura is much increased in those situations in which it is normally present

In a preceding paragraph small masses of lymphoid tissue were described in the septa between the secondary lobules independent of any relationship to the pulmonary vein Such masses are much more frequent in the pleura Here they are often seen situated between a small pleural lymph vessel and the rounded tip of an alveolus located just beneath the pleura These small masses of lymphoid tissue usually contain a considerable quantity of pigment (carbon) It is not uncommon to find phagocytes laden with particles of carbon which they have picked up within the alveolus lying close to or just penetrating the wall of an alveolus on their way to deposit their load in the lymphoid tissue

In other instances these small masses of lymphoid tissue were associated with a radicle of a pulmonary vein which was situated on the periphery of a primary lobule and had its origin from the capillary network in the walls of the sacculi alveolares just beneath the pleura

In many points the results of this study of lymphoid tissue in the human lung in old age coincide with the results obtained by Gardner in his study of experimental pneumonokoniosis, and by H S Willis in his study of spontaneous pneumonokoniosis in guinea pigs

The Vascular Supply of the Lymphoid Tissue in the Rabbit's Lung Since the time of Reisseisen the statement that the lymph nodules and the lymphoid tissue found along the bronchi receive their blood supply from the bronchial artery has been generally accepted In the rabbit, however, I have found that these masses of lymphoid tissue do not receive their blood supply from the bronchial artery but from the pulmonary artery

This has an important bearing on experimental work which involves the lung of the rabbit for any microorganism that is introduced into the venous circulation of the rabbit is conveyed from the right side of the heart directly to these masses of lymphoid tissue by the pulmonary artery As the masses of lymphoid tissue which are associated with the place where the bronchi divide

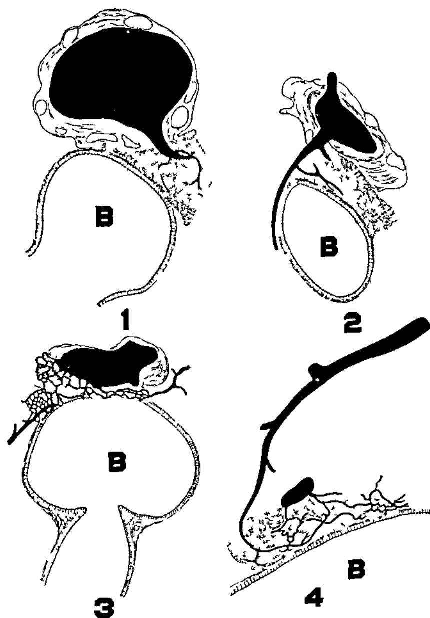


Fig 101

See page 137 for description

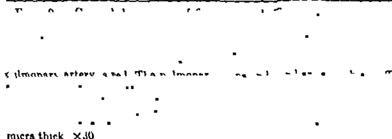
are especially liable to become affected, the present communication will be confined to a description of the various types of arterial distribution to these masses

In Figure 101,1, a short and somewhat stout branch is given off from the main trunk of the pulmonary artery and passes, without branching, directly to the lymphoid tissue, within which it breaks up into small arterioles that eventually end in a capillary network that is distributed throughout the lymphoid tissue The further relation of this capillary network will be shown in connection with Figure 101,3, and Figure 101,4

In Figure 101,2, two small arteries are distributed to the mass of lymphoid tissue These do not arise directly from the main arterial trunk but from a branch of the pulmonary artery which supplies the more dependent sacculi alveolares of a primary lobule

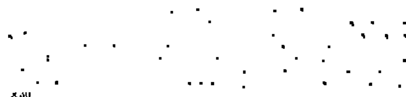
In Figure 101,3, a number of small arterioles are given off from the main trunk of the pulmonary artery and these almost immediately break up into a capillary network within the lymphoid tissue The capillary network thus formed within the lymphoid tissue unites with the capillary network within the walls of the adjoining alveoli to form venous radicles, which in turn unite to form small branches of the pulmonary vein

Figure 101,4, illustrates an entirely different type of the origin of the artery which is distributed to the lymphoid tissue Here it is not a branch which is given off directly from, or in close proximity to, a main trunk of the pulmonary artery, but it is a terminal



micra thick ×30

Fig 2—Camera lucida tracing of a section of a bronchiolus (B) 0 45 mm in diameter just before its division showing the distribution of the artery to the



×30

twig of a branch of the pulmonary artery which, after supplying a primary lobule, penetrates its periphery and passes to the lymphoid tissue The capillaries into which the arterial twig breaks up either empty into a branch of the pulmonary vein or they unite with the capillaries in the walls of the alveoli of the lung

In a few instances a combination of the types represented by Figures 101,1, and 101,3, or of Figures 101,2, and 101,3, has been seen, but thus far the type shown in Figure 101,4 has been found to exist independent of any combination with other types of arterial distribution This may be due to the fact that thus far it has been found in connection with lymphoid tissue associated with bronchi of relatively large calibre More extended study may, however, modify this statement

This study of the arterial supply of the lymphoid tissue in the rabbit's lung shows the importance of a better knowledge of the vascular supply of lymphoid tissue, not only in the lung but also in other organs of the animals used for experimental purposes It may well be that a more careful study of the distribution of lymphoid tissue in the various organs, and of its blood supply, will lead to a better understanding of some of the phenomena associated with experimental inoculations

Summary Pulmonary lymphoid tissue may be peribronchial, periarterial, perivenous or pleural

Lymphoid tissue may occur in the form of lymph nodes, lymph follicles, or small masses of lymphoid tissue

Lymph nodes in the normal lung, are found associated with the larger divisions of the bronchi, and are situated at the place where branching takes place

[illegible] nt in the pleura [illegible] e lymph nodes, [illegible] They may also serve as centers to which the phagocytes carry their collected material

On account of the arrangement of the blood vessels and the relation it bears to them, lymphoid tissue is found most abundant on the periphery of the primary and secondary lobules

There is in old age a definite increase in the lymphoid tissue independent of that which may be produced by inflammatory diseases, the amount of this increase is dependent on the amount of carbon or other irritating particles inhaled

In the rabbit it is the pulmonary artery, not the bronchial artery, that furnishes the vascular supply of the lymphoid tissue

Any microorganism introduced into the venous circulation of the rabbit is conveyed directly to the pulmonary lymphoid tissue by the pulmonary artery

Chapter VIII

THE NERVES

It is due to the painstaking work of Professor O Larsell now of the University of Oregon, that we have a comprehensive idea of the distribution of the nerves and their endings, within the lung I had made a preliminary study of their distribution but when Professor Larsell came to the University of Wisconsin as my assistant professor, I turned the problem over to him telling him that it was his to complete The following account, based largely on his work, will tell how well he has worked the problem Very kindly he has granted me permission to use some of his illustrations showing the various types of nerve endings found in the lung

The lungs receive their nerve supply from two sources the vagi and the sympathetic nerves Each vagus nerve on reaching the back of the root of the lung breaks up into numerous branches which reinforced by fine branches from the second third, and fourth thoracic ganglia of the sympathetic system, form the posterior pulmonary plexus and at the same time send a few fibers to the front of the root of the lung to take part in the formation of the anterior pulmonary plexus

Each plexus gives off fibers which are distributed to the bronchi and pulmonary artery at the hilum On entering the lung these fibers form two main plexuses which are distributed one about the main stem bronchus and its branches, the other about the pulmonary artery and its branches According to Larsell the plexus in the cartilaginous bronchi divides into two portions one, extrachondrial situated external, the other, subchondrial internal, to the cartilages In the non-cartilaginous bronchi the two plexuses unite

along the extrachondrial and the subchondrial plexus, but also along the single network of fibers which continues them distally (Fig 103)

The first afferent receptors within the bronchi are distributed along the epithelium lining the bronchi as free nerve endings (Fig 104) In the angle formed at the point where bronchi branch and at the base of the ductuli alveolares endings of a less diffuse type are found (Fig 105) In the walls of the atria which are lined with flattened respiratory epithelium instead of cuboidal or pyramidal

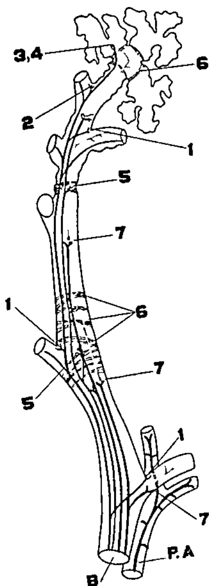


FIG 102 — Scheme of the distribution of the nerves B, bronchus, P A, pulmonary artery, Red, afferent fibers from ending in the epithelium, Brown, afferent fibers from "smooth muscle spindles", Blue, preganglionic efferent fibers, Yellow, postganglionic fibers to bronchial musculature and glands, Green vasomotor fibers to media of pulmonary artery 1, nerve ending in epithelium (Fig 104), 2, nerve ending at point of division of bronchi (Fig 105), 3 and 4, nerve endings in the wall of the atrium (Figs 106 107), 5, nerve ending in muscle spindle (Figs 108, 109), 6, nerve ending in smooth muscle (Fig 111), 7, pericellular network (Fig 110)

epithelium as is the case with the bronchi and bronchioli a very different type of nerve ending is found The nerve fibers leading to this type of ending follow the walls of the bronchioli respiratorii and ductuli alveolares and after repeated subdivision end in a mass



Fig 103 — A ganglion in close apposition to a nerve Small branches of the main nerve can be seen on either side of the ganglion The blood vessel seen in the upper portion of the photograph is a bronchial artery ×150

of branching fibers which form a flattened end organ that is covered by the epithelium lining the atrium while on the other side the ending rests against the framework of the atrial wall Certain of these endings appear to have a delicate capsule (Fig 106) while others are simply covered by the atrial epithelium (Fig 107)

The bronchial musculature extends as far as the atria in the form of a geodesic network which is supplied with two types of nerve endings Large myelinated nerves which divide into numer

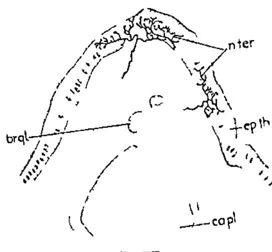


Fig 104—Nerve ending in epithelium at the division of bronchus into bronchi about 1 mm in diameter Only that part of the endings visible in one section was drawn n tr nerve termination epith epithelium ca pl, cartilage br gl, bronchial gland From a child 8 months old ×177

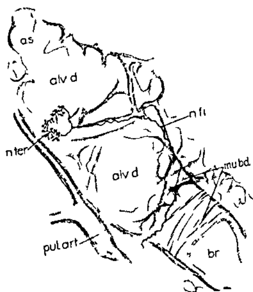


Fig 105—Nerve ending at point of division of a bronchiolus respiratorius into a ductulus alveolaris a s sacculus alveolaris alv d ductulus alveolaris n ter, nerve termination n fi nerve fiber mu bd bands of bronchial muscle pul art arteria pulmonalis br bronchus without reference to order From a child 8 months old ×102



Fig. 106.—Nerve ending in the wall of an atrium. From a child 8 months old. ×356

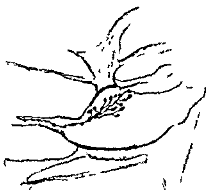


Fig. 107.—Free nerve ending in the wall of an atrium. From a child 8 months old. ×546



Fig. 108.—Smooth muscle nerve spindles in bronchial muscle bands. *n.fi.*, nerve fiber; *m.fi.*, smooth muscle fibers; *n.ter.*, nerve termination; *mu.bd.*, bands of bronchial muscle. From a child 8 months old. ×546

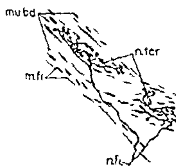


Fig. 109.—Smooth muscle spindles in small bronchial muscle bands. *mu.bd.*, bands of bronchial muscle; *m.fi.*, smooth muscle fibers; *n.ter.*, nerve termination; *n.fi.*, nerve fiber. From a child 8 months old. ×356



FIG. 110.—Ganglion cells showing pericellular network from pre-ganglionic fibers. From child 8 months old. ×346

ous branches lead to the first of these endings. Each muscle band is supplied with a separate branch which forms on it a spindle-shaped termination (Figs. 108, 109); they have not, however, been found in the bronchioli respiratorii or the ductuli alveolares.

Small myelinated fibers, which are probably preganglionic, end in a network about clusters of ganglionic cells (Fig. 110). From these ganglionic cells non-myelinated fibers are given off which are distributed to the smooth muscle bands, where they terminate as motor endings (Fig. 111).

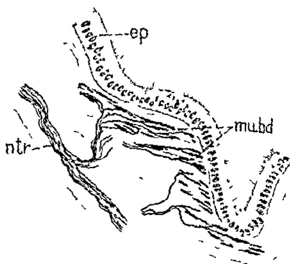


FIG. 111.—Nerve ending in smooth muscle bands. n t r, nerve trunk; mu bd, smooth muscle bands; ep, epithelium. ×225. (Larsell.)

Chapter IX

THE PLEURA

The pleura pulmonalis plays an important part in marking out the lung into secondary lobules by sending prolongations, the septa, into its substance. It is only in lungs which possess a thick pleura (Fig 112, A) as is the case, for example in the lung of the pig, the ox, and man, that secondary lobules can be demonstrated. In the rat, the rabbit, the cat, and the dog, common laboratory animals, the lungs are covered with a thin pleura (Fig 112 B) consequently, no septa are found.

The Pleura in Man The pleura pulmonalis is a reflexion of the

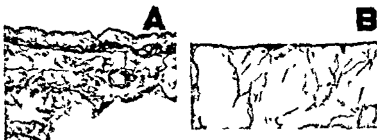


Fig 112 —Illustrates the difference between a *thick* pleura (A) and a *thin* pleura (B). A is from the lung of an adult man. B is from the lung of a rabbit. Both are ×200

serous membrane which covers the viscera contained within the thoracic cavity. It is usually described as a serous membrane covered with a layer of mesothelium which rests on a subserous layer of connective tissue that is composed of collagenous fibers and a few elastic fibers. Within this subserous layer the blood vessels, lymph vessels and nerves are to be found.

Mesothelium The mesothelial layer, as its name implies, consists of mesothelial cells. Since the time of Oedmansson and v Recklinghausen certain appearances characterized as preformed openings found between the cells lining the so-called serous cavities have been designated as stigmata and stomata. As one reviews the literature of the subject it is seen that, while at first the opinion of v Recklinghausen influenced the earlier investigators to accept these appearances as normal structures, later studies with

improved methods have led many to declare that they are not normal structures but artifacts The author denied their presence in

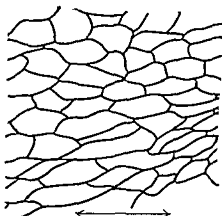


FIG 113 —Mesothelium from the *pleura parietalis* (intercostalis) which has been stretched in the direction indicated by the arrow Note the elongated shape of the cells ×210

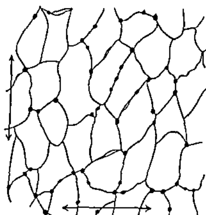


FIG 114 —Mesothelium from the *pleura parietalis* (intercostalis) which has been strongly stretched in the directions indicated by the arrows Note the ' stigmata and the spaces caused by the separation of the cells ×210

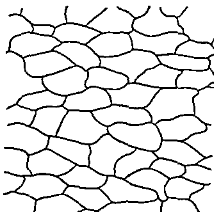


FIG 115 —Mesothelium from the *pleura parietalis* (intercostalis) which

mata and openings between the cells ×210

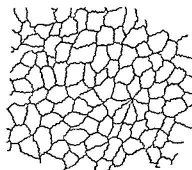


FIG 116 —Mesothelium from the *pleura pulmonalis* Note the total absence of stomata stigmata and openings between the cells The specimen was fixed *in situ* The center of the rosette of cells seen near the middle of the illustration is the place where stomata are said to be always present ×210

the pleura pulmonalis in 1896 and his observation has been confirmed by later investigators, v Ebner saying *"Ich habe ebenfalls vergeblich nach solchen gesucht* ' The methods of preparation made

use of by the earlier and to a certain extent by some of the later investigators have been contributive to the production of these artifacts for example the rough handling attendant on the removal from the body of the part to be acted on by argentic nitrate or what is even greater violence to the tissue the stretching of the part to be studied over cork glass or vulcanite rings or the spreading of the membrane over the edge of a shallow glass dish and pouring over it the solution of argentic nitrate The strength of the argentic nitrate solution also has its influence the stronger the solution the greater the number of these artifacts These statements can be substantiated as follows If a portion of the wall of the thorax be removed and stretched in one direction slightly before being acted upon by argentic nitrate the boundary lines of the mesothelium will remain intact but will show distortion in the direction of the force applied (Fig 113) if a second portion be removed and stretched violently in two directions (Fig 114) the usual appearance of dots and intercellular spaces will appear when treated with argentic nitrate if instead of removing the part to be stained the entire process be carried on *in situ* the mesothelium will retain its normal form and the boundary lines will be intact (Fig 115) The results obtained when the pleura pulmonalis is thus treated are especially satisfactory (Fig 116) though it is a more delicate subject than the pleura costalis

Elastic Layer Of the descriptions of the elastic fibers in the human pleura pulmonalis that by Linser and that by Letulle are deserving of special attention the former is given from the normal the latter from the pathological standpoint

Linser describes an elastic layer situated immediately beneath the pleural epithelium (mesothelium) that is made up of fibers which cross one another at an acute angle This is followed by a layer of connective tissue in which bundles of collagenous fibers are interspersed with fine elastic fibers Still deeper in the pleura there is a second layer of elastic fibers which runs parallel to the surface of the lung the individual fibers of which anastomose with the elastic fibers in the walls of the alveoli

The description given by Letulle is in general more accurate than that by Linser Letulle finds that there is on the outer surface of the pleura pulmonalis a layer of flattened endothelial (mesothelial) cells which rests on an avascular sub-endothelial (mesothelial) connective tissue Beneath this layer there is a *limitante élastique externa or superficielle* which is comparable to the *elastica interna* of the blood vessels this forms a part of his *conjunctivo-vasculaire* membrane of the pleura within which there are numerous blood vessels and lymph vessels Still deeper in the pleura there is a

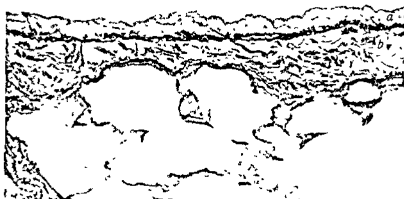


Fig. 117.—Normal pleura pulmonalis from the human lung. Selective staining of the elastic fibers. a, submesothelial layer; b, areolar layer. The elastic layer is the layer of compact fibers between a and b. ×200

limitante élastique profonde or *externa* which is reinforced by fibers from the adjacent pulmonary alveoli.

This deeper layer of elastic fibers, the *limitante élastique profonde* of Letulle, is not to be considered a part of the pleura; *it belongs to the walls of the subjacent alveoli.*

The surface of the pleura is, as both Linser and Letulle have



[illegible] lung. Selec-

×200.

and covered by a layer of thin flattened mesothelium which, as stated by Letulle, rests on an avascular layer of connective tissue. This submesothelial layer is made up of collagenous fibers that in some instances are interspersed with delicate elastic fibers which are derived from the underlying elastic layer, and a network of reticulum that is especially well developed just beneath the layer of mesothelial cells forming its basement membrane.

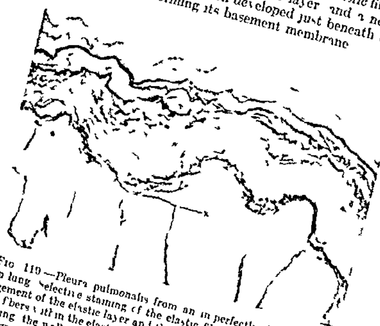


Fig 119.—Pleura pulmonalis from an imperfectly distended human lung. Selective staining of the elastic fibers. Note the loose arrangement of the elastic layer and the presence of bundles of collagenous fibers within the elastic layer. Due to the imperfect distention of the lung, the walls of the alveoli in the central portion of the photomicrograph are cut obliquely, thus bringing into view the network of elastic fibers in that portion of their walls which abuts upon the pleura. At x an anastomosing elastic fiber within the alveolar wall can be seen joining the subpleural network. ×200.

The elastic layer is made up almost exclusively of elastic fibers. Bundles of collagenous fibers pass through the meshes of the elastic fibers, and a limited amount of reticulum can be demonstrated. A few fine fibers are given off into the submesothelial layer, and anastomosing fibers pass through the areolar layer to join the network of elastic fibers in the walls of the alveoli which abut upon the pleura and also to join the elastic fibers within the areolar layer. When the lung is distended the elastic layer appears as a compact layer (Figs. 117, 118), but when the lung is imperfectly distended the elastic layer often appears as though it were made up

of two portions, between which bundles of collagenous fibers may be seen (Fig 119)

Neither Linser, Favaro, nor Letulle considers the elastic layer as a separate layer Both Linser and Letulle consider it as a part of the areolar layer of the pleura—the *conjonctivo-vasculaire* layer of Letulle Favaro associates it with the sub mesothelial layer, and calls the combined layers the *ipopleura* In some animals, for example, the horse, the elastic layer is of such thickness that it is possible to dissect it off as a separate lamina

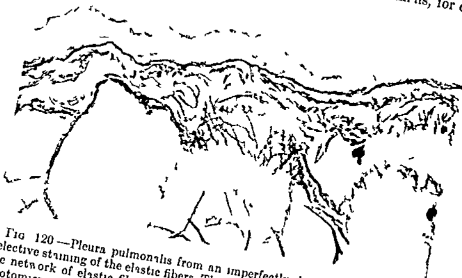


Fig 120—Pleura pulmonalis from an imperfectly distended human lung Selective staining of the elastic fibers This section was cut in such a plane that the network of elastic fibers in the wall of the alveolus in the center of the photomicrograph shows clearly Immediately below this subpleural network of elastic fibers the elastic fibers in the walls of the adjoining alveoli can be seen ×200

Areolar Layer. The most important layer in the human *pleura pulmonalis* is the areolar layer for within it the blood vessels lymph vessels and nerves are situated This layer is made up of bundles of collagenous fibers between which elastic fibers pass that anastomose on the one hand with the network of the elastic layer, and on the other hand with the network of elastic fibers in the walls of the underlying pulmonary alveoli The arrangement of these anastomosing fibers is of interest, some of them have a direction perpendicular to the surface of the pleura (Fig 118), while others pass obliquely through the areolar layer

The interesting question now arises Is the *limitante élastique profonde* of Letulle to be considered a part of the pleura or does

it belong to the underlying alveolar walls? The opinion has already been expressed that it belongs to the alveolar walls

If the wall of an alveolus which is situated directly beneath the pleura be cut transversely a selective stain for elastic fibers will show a thin line of elastic fibers within the alveolar wall which may present a slightly beaded appearance due to the sectioning of anastomosing branches (Figs 118 120)

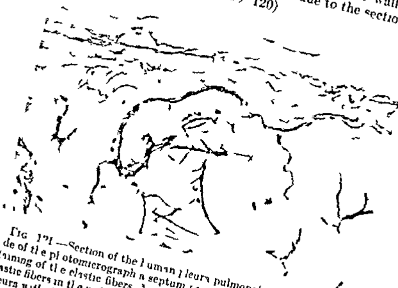


Fig 121 —Section of the human pleura pulmonalis showing on left side of the photomicrograph a septum passing into the lung Selective staining of the elastic fibers Note the continuance of the network of elastic fibers in the walls of the alveoli beneath the areolar layer of the pleura with that in the alveolus immediately beneath the epithelium The network of elastic fibers in the wall of the alveoli which do not come in contact with the pleura is seen to be the same as that in the alveolar walls which *do* come in contact with the pleura (Compare with Figures 119 and 120 ×100

When an alveolus is cut in such a manner that the elastic fibers in its lateral walls appear in the section they can be seen to join the network of elastic fibers in that portion of the alveolar wall which abuts upon the pleura (Fig 119 x)

If a subpleural alveolus be cut in such a plane that the network of elastic fibers in the wall which abuts upon the pleura comes clearly into view (Fig 120) it will be seen that it corresponds to the network in the alveolar walls which do not abut upon the pleura (Fig 121 x)

If a section be cut so that it includes a septum and if the wall of the alveoli adjacent to the pleura and to the septum be at the

same time cut transversely it will be seen that the network of elastic fibers in the alveolar walls beneath the areolar layer of the pleura is continued into the walls of the alveoli which are situated immediately beneath the septum (Fig 122) The elastic fibers in the alveolar walls which abut upon a septum are not considered a part of the septum such being the case why should the elastic network in the alveoli which abut upon the pleura be considered a part of the pleura?

Neither the statement by Linser that there is a second layer of elastic fibers which runs parallel to the surface of the lung and gives off fibers which anastomose with those in the alveolar walls nor

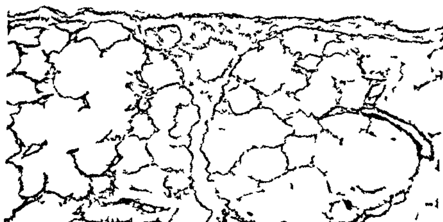


Fig 122 —Section of the human *pleura pulmonalis* which includes a septum situated between two secondary lobules *The continuation of the elastic fibers* ... th the ... of the alveol which ... empty lym... the septum

that by Letulle that the *limitante élastique profonde* is reinforced by fibers from the subjacent alveoli seems to describe the actual relationship It is true that anastomosing branches connect the network of elastic fibers in the walls of the alveoli with those in the areolar layer and also with the fibers in the elastic layer These anastomosing fibers have a very definite purpose they serve to tie the pleura proper to the walls of the alveoli and at the same time to assist in respiration It is also quite probable that the elastic fibers within the areolar layer of the pleura have a similar action to those within the pulmonary walls since due to the continuance of the elastic fibers of the blood vessels and of the lymph

vessels with these fibers, they must exert an influence on the circulation of the blood and lymph

It has been shown that in the normal pleura anastomosing fibers extend between the network of elastic fibers in the walls of the alveoli and the elastic fibers within the areolar and elastic layers of the pleura In the case of a bleb however, there has been a rupture of these anastomosing fibers and the pleura proper has been separated from the walls of the underlying alveoli

What has caused this separation? In every case that I have had an opportunity to study blebs have been associated with a well-

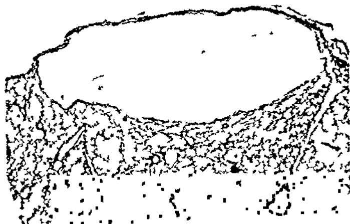


Fig 123 —Section through a small bleb showing a hemorrhage into the bleb The extension of the bleb has been arrested by the septum on the right of the figure ×7 5

marked emphysema The manner in which a bleb is formed resembles that if indeed it be not the same which takes place in an interstitial emphysema namely, a rupture of the wall of an alveolus which allows the air to escape in this instance into the areolar layer of the pleura This occurs at a point where, from some cause the elastic fibers in the alveolar wall have given way possibly from having been stretched to the breaking point

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aneurysm extends along the wall of an artery Its extension may be arrested where the septa, which mark out a secondary lobule,

leave the pleura (Fig 123), it may extend over a number of secondary lobules, or it may be still more extensive, as described by Watson

Blood Vessels of the Pleura. In the opening paragraph of this chapter attention was directed to the difference between lungs with a thick pleura and those with a thin pleura This difference influences the vascular supply to the pleura

In lungs with a *thick* pleura, septa extend from the pleura into the lung, and it is along these septa that branches of the bronchial artery reach the pleura On reaching the pleura, branches are given off which form the *vasa vasorum* of the lymphatics (Fig 88)

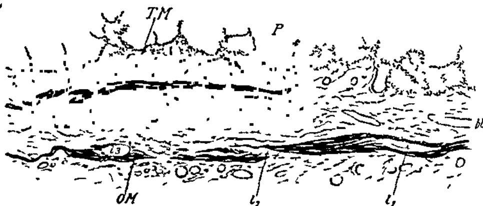


FIG 124 —Smooth muscle in the visceral pleura of the human lung The dark strands are smooth muscle OM superficial musculature TM, deep layer of muscle P parenchyma of the lung l_1 to l_3 lymphatics (After Baltisberger)

Eventually the bronchial artery breaks up in the areolar layer into capillaries which unite to form the radicles that take part in the formation of those branches of the pulmonary vein that arise from the pleura and pass along the septa into the depth of the lung (Fig 61)

If, as sometimes stated, the capillaries derived from the bronchial artery anastomose within the pleura with the capillaries into which the pulmonary artery breaks up, why is it that in the case of pleural blebs which are formed by a splitting of the pleura, and are often very extensive (*vide* Watson), no hemorrhage into the space occurs? In such cases as I have seen in which a bleb contained blood, the hemorrhage proceeded from a small branch of a pulmonary blood vessel *situated in the substance of the lung* a short distance beneath, or to one side of, the bleb, and found its way into the bleb through the torn alveolar walls (Fig 123)

In lungs with a *thin* pleura there are no septa and, consequently, the distribution of the bronchial artery to the pleura is confined to a small zone in the neighborhood of the hilum Elsewhere it is the pulmonary artery that supplies the pleura (Fig 87)

Muscle in the Pleura Strands of smooth muscle have been described, notably by Baltisberger, as being present in the human pleura I have found similar strands of smooth muscle, but in each instance serial sections showed that they belonged to the walls of either blood vessels or lymph vessels If Baltisberger's figure (Fig 124) be studied it will be seen that in every instance his strands of



Fig 125 —Section perpendicular to the pleura of the guinea pig The bundles of smooth muscle cut transversely are situated between elastic fibers (black) which extend through the entire thickness of the pleura ×400

smooth muscle are associated with lymphatics and lymphatics have smooth muscle in their walls Sections which cut branches of the bronchial artery also show smooth muscle strands similar to those illustrated by Baltisberger

The only animal in the pleura of which I have found smooth muscle bands is the guinea pig their presence has been previously described by Klein and by Lazaro In sections cut perpendicular to the pleura of the guinea pig (Fig 125) these bands can be readily recognized

Each lobe of the guinea pig's lung is enclosed in a network of smooth muscle This network starts at the hilum and radiating

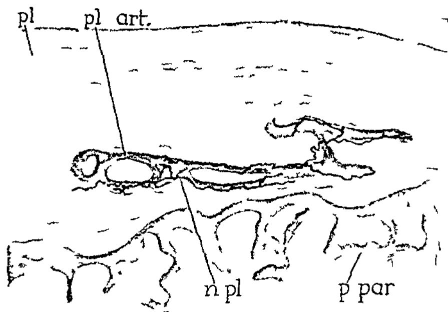


Fig 128 —Vasomotor fibers n pl accompanying branches of the bronchial artery pl art within the human pleura p par pulmonary parenchyma ×300 (Larsell)

are given off and these still further branch the final twigs end in a small terminal knob



Fig 129 —Efferent nerve and nerve endings human pleura ×300 (Larsell)

Corpuscles similar to those described by McLaughlin were found by Larsell in the human pleura but he failed to recognize them as nerve endings The fibers connected with them could only be followed for short distances and they lacked the varicosities which characterize true nerve fibers

Chapter X

KEY POINTS

By studying the various diagrams in the preceding chapters, especially Figure 61 and Figure 102, definite points can be recognized where certain structures are constantly found. These points, five in number, I have designated "Key Points," because they are of assistance in understanding the architecture of the lung (Fig. 130, 1, 2, 3, 4, 5). The five points are as follows:

(1) The place where radicles of the pulmonary vein arise from the pleura.

(2) The place where radicles of the pulmonary vein arising from the distal end of a ductulus alveolaris join a venous trunk situated on the periphery of a primary lobule.

(3) The place where radicles of the pulmonary vein arising from the place where bronchi or bronchioli divide join a larger trunk which may or may not be situated on the periphery of a secondary lobule.

(4) The distal end of a ductulus alveolaris.

(5) The place where a bronchus or a bronchiolus divides.

While the following statements are based on what may be found in the human lung, they are also applicable, with but slight modification, to all mammalian lungs.

At Point 1 connective tissue septa are given off from the pleura; branches of the bronchial artery pass to the pleura and break up into a network of capillaries; the small venous radicles which arise from this network of capillaries unite to form a small vein that passes along the septum into the depth of the lung; the lymphatics which are situated in the septum join the plexus of lymphatics in the pleura, the direction of the lymph flow being towards the pleura as indicated by the position of the valves (Fig. 61); lymphoid tissue is found; nerve trunks are often found. (Point 1 must be modified in the case of animals with a thin pleura, for no septa are present.)

At Point 2 the small vein arising from the distal end of a ductulus alveolaris joins a larger trunk; the lymphatics which accompany this vein join the plexus of lymphatics about the larger venous trunk; a small amount of lymphoid tissue is found.

At Point 3 the vein arising from the place where a bronchus or bronchiolus divides joins a large venous trunk; the lymphatics accompanying this vein join the lymphatic plexus about the large

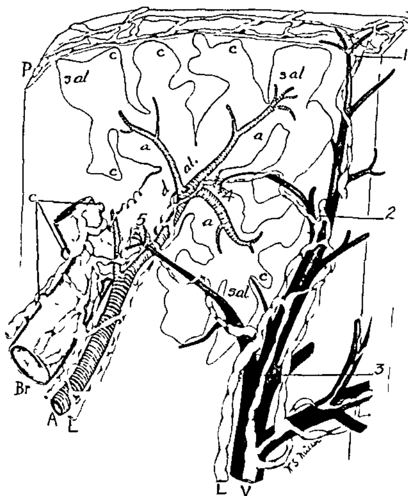


FIG 130—P, pleura, Br, bronchiolus respiratorius which divides into two ductuli alveolares (d al), only one of which is carried out in detail, a a a, three atria, each of which has a number of sacculi alveolares (s al), opening into it around the periphery of which are the alveoli pulmonum, c Alveoli are also connected with the bronchiolus respiratorius, ductulus alveolaris and the atria A., pulmonary artery which divides into three atrial branches and each atrial branch divides into branches which are distributed to the sacculi alveolares these latter branches give origin to the capillary network in the walls of the air spaces L, lymphatics, V, pulmonary vein and its branches of origin, 1, 2, 3, 4 5, the key points described in the text

venous trunk there is a larger amount of lymphoid tissue than is present at Point 2

At Point 4 the only veins found within the primary lobule take their origin In young and middle aged individuals there is a small amount of lymphoid tissue which becomes more pronounced in old age The last of the lymphatics which accompany the subdivisions of the bronchial tree pass on the one hand to the veins which take their origin at this point on the other hand they form an anastomosis with the lymphatics which accompany the pulmonary artery The smooth muscle in the walls of the ductulus alveolaris forms a sphincter about the openings leading into the atria smooth muscle ceases to be present sensory nerve endings are found

At Point 5 which may be wherever a bronchus or a bronchiolus divides anastomoses between the lymphatic plexus in the given division of the bronchial tree and the plexus about the pulmonary artery take place one or more lymphatics pass to the pulmonary veins which have their origin at this point lymphoid tissue in varying amount is present and where the first two or three branches leave the main stem bronchus lymph nodes are found sensory nerve endings are present cartilage when present is found

In addition to these five points attention should be paid to the change in the vascular supply of the final divisions of the bronchial tree *from* the bronchial artery *to* the pulmonary artery With the appearance of alveoli along the bronchioli the bronchial artery as a nutrient vessel to the bronchial tree disappears and the network of capillaries in which it terminates joins the network of capillaries derived from the pulmonary artery and the bronchioli respiratorii the ductuli alveolares and the air spaces connected with them receive their blood from the pulmonary artery This transitional zone is the one in which tubercles are most prone to develop Possibly a retardation of the circulatory force at this point may be a determining factor

While Figure 130 and the accompanying descriptive text reproduces much that is contained in preceding chapters it has been found that this condensed form has proved useful to students of lung structure The nerves bronchial artery and capillaries have been omitted to simplify the diagram

Chapter XI

HISTORICAL SKETCH

If the literature on the structure of the lung be reviewed it will be found that by many authors the term lobule is applied to those areas which are sharply marked out by connective tissue septa in the lung of the ox and of the child, but less distinctly marked out in the lung of adult man In some animals, as for example the cat or the rabbit, this marking out of well defined areas is absent This has led to much confusion and authors differ in their descriptions of what constitutes a lobule, some even beginning their descriptions with a secondary lobule and ending with that of a primary lobule, and *vice versa* Still, whatever its constitution, a lobule is considered the unit of construction Rossignol has well stated this fact when he says

Le poumon des mammifères est l assemblage d'un grand nombre de lobules semblables appendus aux extrémités d'un arbre bronchique commun Le problème de la texture de cet organe se réduit donc à déterminer celle du lobule

In the following pages I shall confine myself to the arrangement of the air spaces, and reproduce in chronological order some of the descriptions and diagrams to which I have access

The description of the lung as given by *Vesalius in 1543 summed* up the knowledge of its structure previous to and at his time, he says

Pulmonis substantia, caro est mollis, fungosa, rara, levis, aërea ac vetut ex spumoso sanguinie spumave sanguinea, concreta, multisque vasorum germinibus scatens

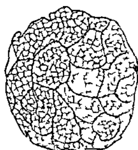
Rendered into English it reads "The substance of the lung is a soft spongy, thin, light, airy flesh, as though composed of frothy *blood or bloody froth, and filled with many* branches of vessels" This remained the accepted description until the time of Malpighi

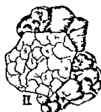
MARCELLO MALPIGHI (1628–94)

Malpighi proved by means of injections of mercury into the blood vessels that no communications existed between them and the ramifications of the bronchi He was the first to recognize the presence of pulmonary lobules The lobules, surrounded by their proper membrane and supplied with common vessels were attached to the small branches of the trachea (secondary lobules)

He described the parenchyma of the lung as consisting of an assemblage of delicate membranes made up of vesicles which were round and sinuous, formed by the terminations of the bronchi, and compared them to the cells of the honey-comb (Fig 131) All the vesicles communicated with each other, thus giving to the lung a sponge like appearance Malpighi saw vesicles not only at the end of the bronchi but also along their walls i e lateral vesicles

Tab I.







the trachea and pulmonary vessels (After Malpighi)

Besides the vesicles which made up the lobules Malpighi described a second set situated in the interlobular tissue These were smaller than the vesicles of the lobules but they intercommunicated with each other and mutually took part in respiration He evidently had produced an artificial interstitial emphysema by overdistending the lung with air

Malpighi probably saw, but did not recognize, lymphatics in the lung for he says he has seen "certain black points which mark out as with a thin line the whole extent of the interstitia" The black lines were probably pigment deposited along the lymphatics "The same pigmentation is seen in the glands continued at the sides of the trachea aspera

The above abstract is from the first of the two letters Malpighi wrote to Borelli on the structure of the lung In his second letter he described the capillary network extending between the artery and

vein and so completed the circulation of the blood through a definite system of vessels rather than the indefinite "porosities of the tissues" as described by Harvey

THOMAS WILLIS (1622-75)

Willis studied the structure of the lung by injecting independently the bronchi and blood vessels with mercury or with various colored liquids which easily congealed He found that attached to the small branches *(bronchi) of the "aspera arteria" (trachea) there were "little lobes" and that the interspaces between these* little lobes were filled with a "Membrane" In other words he recognized what are now termed the secondary lobules of the lung (Fig 132) On cutting open one of the leaf-like little lobes he found that after the bronchial twig with which it was connected had penetrated into its interior, it broke up into a large number of finer branches which bore on their terminations minute bladders or ampullae (Fig 132) These bladders did not communicate with each other as was the case with the vesicles of Malpighi's figure, neither did they possess the polygonal form given them by Malpighi, but they were separate, independent structures*

Besides these little bladders, Willis described in the interspaces between the little lobes "certain little bladders, transparent and very thin," the purpose of which he explains as follows

interval between them

In another place he says that if one make a small hole in ' one of these interspaces with the point of a knife, and blow into it *through a pipe, presently that whole lobe will be very much distended, every interspace being puffed up* " By this procedure Willis produced an artificial interstitial emphysema

Willis also recognized what are now termed bronchioli respiratorii for he found small non cartilaginous bronchi that had in the interstices between certain ligaments (smooth muscle bands?)

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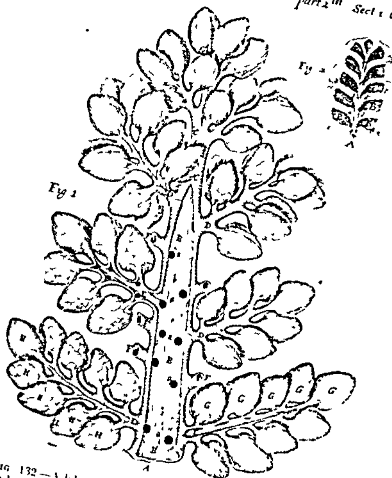


Fig 132 — A lobe of the lung showing its subdivisions A Main stem bronchus D Bronchus passing to the subdivisions of the lobe G. The secondary or little lobes within which the little bladders are situated These are arranged along the bronchus which enters the little lobe in the same manner as the little lobes are arranged along D The small figure in the upper right shows how the little lobes appear when the membranous interspaces are blown up with air (From T Willis)

"small bladdery little cells" (*cellulas vesiculares*) He quite aptly compares these bronchioli to the colon of a mouse (*muris colo intestino*)

The advance made by Willis over the work of Malpighi consisted in the recognition of definite areas within the lung surrounded by connective tissue, which contained the finer ramifications of the bronchi, each ultimate ramification bearing on its extremity a "little bladder" These little bladders were entirely independent of each other and differed from the polygonal cells of Malpighi which communicated with each other

Accompanying these areas, or little lobes, were branches of the pulmonary artery and pulmonary vein, nerves, and lymphatics Willis had worked out, so far as the methods at his command would permit, a unit of construction which also included the gross distribution of the bronchial artery

FRANZ DANIEL REISSEISEN (1778–1828)

The work of Willis was quickly forgotten and I have not been able to discover any further original work, accompanied by illustrations of the structure of the lung until the time of Reisseisen He received the first prize of the Royal Academy of Berlin for his dissertation on the *Structure of the Lung* This was first published without illustrations, in 1808, in 1822 a beautifully illustrated edition was issued under the direction of K A Rudolphi which contained parallel columns of German and Latin text, the latter by J F C Hecker At the same time that Reisseisen received the first prize v Sommering received the second prize, but unfortunately his dissertation was never issued with illustrations

In the meantime notable theoretical discussions had been published by Helvetius (1718) and by Haller (1761), the main question being the existence of the system of vesicles described by Malpighi Helvetius denied their existence and described the lung as consisting of cellular tissue derived from the pleura "in which the air brought by the ramifications of the bronchi is diffused in the same manner as the blood is diffused in the spleen of the sheep or in the corpora cavernosa" *Haller supported Helvetius in some* of his contentions but states that the theory of Helvetius was not generally accepted and that the existence of *air vesicles* as described by Malpighi was the prevailing opinion With this digression we will now return to the work of Reisseisen

Reisseisen followed the method introduced by Willis and injected mercury into the bronchi He chose for his study the margins of the lung By careful pressure with the handle of his scalpel

he caused the mercury to appear at the thin border of the lung. When this was examined under a dissecting lens he noted that "the mercurial column divided quite regularly into cylindrical branches which became proportionally finer, more numerous, denser, and shorter, until they reached the margin of the lung, where they appeared as hemispherical elevations beneath the pleura" (Fig. 133).

He placed a portion of the margin of the lung prepared as described in the preceding paragraph between two pieces of glass and after applying careful pressure until the mercury was driven to the extreme end of the bronchi examined it under the microscope and found that the terminal branches were so short that they had a hemispherical appearance (Fig. 133).

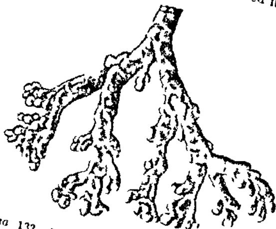


Fig. 133.—Bronchi showing that their endings had a hemispherical appearance. (Reisseisen.)

In another place he describes the bronchi as constantly giving off new branches, which became proportionally narrower, finer and more numerous, until finally, on the most extreme divisions of the branching, they terminated in a blind ending. From this he concludes that all the branches of the bronchi terminate as blind endings and that it is the sum total of these blind endings that constitutes the so-called vesicles of the lung.

This is practically a revival of the description given by T. Willis. It differs from it, however, in that Reisseisen gives to the bronchi blind cylindrical endings, while Willis described them as ending in "little bladders."

EVERARD HOME (1763–1832)

Home did not agree with either Willis or Reisseisen in their statements that the bronchi *ended either in a saccular dilatation or blindly* He says *The cells of the human lungs are not dilatations of the bronchial tubes but are regular cells in which the tubes terminate* His description is somewhat vague and his illustrations still more so He evidently returned to the theory of Malpighi for he says The substance of the lungs interstitial to the cells when dried became transparent and was found to be composed of a smaller order of cells with transparent coverings that freely com*municated with one another as well as with the cavity of the large cell they surrounded* (Fig 134)

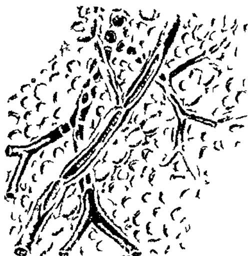


FIG 134 —Shows the structure of the human lung immediately surrounding the air *cells* The interstitial substance between the cells Home says consists of small cells everywhere opening into one another and communicating with the large ones The arteries and veins injected The veins are shown in solid black and a portion of the wall of the artery has been removed Lymphatics indicated by the string of oval bead like bodies *(Home)*

AUGUST LEREBOULLET (1804–65)

The trachea divides and subdivides into numerous branches and their sub divisions which terminate in culs de sac without experiencing any sensible dilatation

The cells or rather the terminal capsules are very numerous They are distinct from one another and do not communicate except through the bronchial canal *of which they are the termination*

The union of a certain number of bronchial ramuscles proceeding and these *lobules* which the organ of

P A E *BAZIN (1807–78)*

Bazin confirmed the observations of Reisseisen He found that cellular or vesicular tissue in which the bronchi were considered

to terminate was only the continuation of the successive ramifications of the bronchi themselves

He disagreed with the theory advanced by Bourgery that the bronchi terminated in a series of branching and anastomosing canals designated by Bourgery labyrinthal canals On the contrary, he found that the bronchi after numerous divisions and subdivisions terminated by giving rise to short branches which ter-

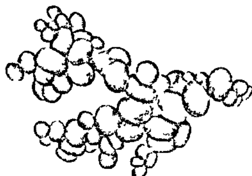


Fig 135—Enlargement of a portion of Lereboullet's Figure 2

minated in culs de-sac ' These are the extremities of the ramifications and it is the enlargements that they present when they are distended, that the majority of the anatomists have taken for cells or vesicles

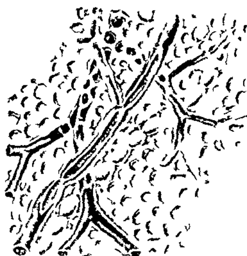
MARC JEAN BOURGERY (1797–1849)

Bourgery disagreed with Bazin and opposed the description of the finer structure of the lung as expounded by Willis and Reisseisen He did not believe that there were any vesicles in the lung but that there existed a series of canals which anastomosed with each other There does not exist in the lung either cells or vesicles but aerial capillary canals The aerial capillary is not a *cellule* or vesicule, but a *canal* ' From this thesis he developed an entirely novel and original theory

These canals, whatever their reference to the pleura, the inclination of the section upon which one observes them, appear equally varied in direction All these canals are very tortuous and inosculate at the

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F g 134 —Sh … everywhere opening into one another and communicating with the large ones The arteries and veins injected The veins are shown in solid black and a portion of the wall of the artery has been removed Lymphatics indicated by the string of oval bead like bodies (Home)

AUGUST LEREBOULLET (1804–65)

The trachea divides and subdivides into numerous branches and their subdivisions which terminate in culs de sac without experiencing any sensible dilatation

The cells or rather the terminal capsules are very numerous They are distinct from one another and do not communicate except through the bronchial canal of which they are the termination

The union of a certain number of bronchial ramuscles proceeding from a single branch forms the pulmonary lobule and these lobules by their agglomerations constitute the lobes of which the organ of respiration is composed (Fig 135)

P A E BAZIN (1807–78)

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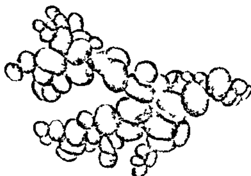


Fig 135 —Enlargement of a portion of Lereboullet s Figure 2

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extremities and upon their contour the one in the other by a great number of orifices (Fig 136)

No canal gives the idea of a cul-de sac or caecum These canals give the idea of a space well divided into thousands of tortuous branches, incessantly continuous within itself, and *where there is nothing terminal* except the orifice of entry, where the outlet is found likewise brought back, it is, in a word, the picture of a true labyrinth It is this which has made me name these conduits *aeriferous labyrinthal canals*

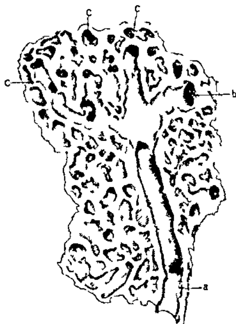


Fig 136 —Termination of a bronchial canal which if it were injected with mercury would reproduce the coeca in the trefoil of Reisseisen a bronchial capillary canal b its continuation c c c trifid sinus opening into the labyrinthal canals Pulmonary artery indicated by oblique lines Pulmonary vein stippled (After Bourgery) ×22

JOACHIM ALBIN GIRALDES (1808–75)

Giraldes studied the lung by means of maceration, dissection and corrosion, and reached the conclusion "that the bronchi do not communicate with each other, that the disposition in the form of a labyrinth does not exist, and consequently that the opinion of M Bourgery is not true " In this statement he supports the opinions expressed by Reisseisen and by Bazin

THOMAS ADDISON (1793–1860)

Addison examined the structure of the lung in every possible way he could devise, yet he always failed to find any bronchial tubes ending in culs-de-sac on the other hand, he always saw air cells communicating with each other in every section he made ' The bronchial tubes, after dividing into a multitude of minute branches which take their course in the cellular interstices of the lobules, terminate in their interior in branched air passages and freely communicating air cells ' (Fig 137)

Addison comments on the synonymous use of the terms air vesicles and air-cells and says that strictly speaking *an air vesicle is an air bubble** and may exist either in or out of a pulmonary cell In fetal lungs neither air bubbles nor air cells exist but with the establishment of respiration the air drawn into the lungs inflates all the lobules to two or three times their previous size and the intralobular bronchial ramifications undergo a very important change The walls of these bronchial ramifications are

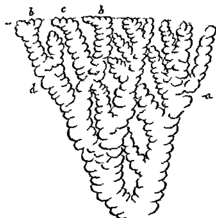


Fig 137 —Intralobular bronchial ramifications partially inflated and highly magnified (a) *Cul-de sac* terminations lying against the lateral inflations of adjoining branches (b b c) The multilocular culs-de-sac at the surface of a lobule (Addison)

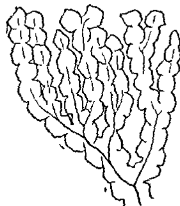


Fig 138 —Shows the cells formed upon the intralobular bronchial branches with polyhedric figures formed by pressure (*Addison*)

very delicate and oppose an unequal degree of resistance to the

metry of their branched arrangement is lost or obscured The mutual compression exerted by the globular inflations of one branch on those of adjoining branches causes them to assume a pentagonal or hexagonal form (Fig 138)

GEORGE RAINEY (1801-84)

Rainey describes the lungs as being made up of bronchial tubes bronchial intercellular passages and air cell The bronchial tubes

* Italics mine W S M

ramify in the substance of the lungs and, "in the human lung having arrived within about one-eighth of an inch of its surface

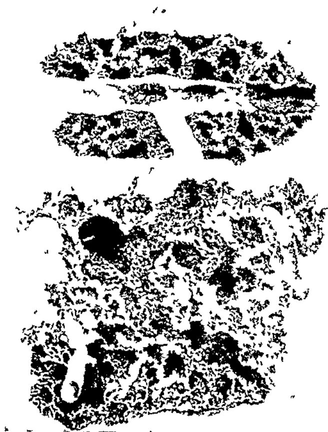


Fig 139—Rainey's description of his figures Fig 1 Shows the abrupt termination of a bronchial tube in a bronchial intercellular passage (a) The bronchial mem-

the (lining) membrane terminates, but somewhat abruptly (Fig 139), after which the passages conducting the air continue in the same direction as the bronchial tubes, of which they are the con-

tinuation but without having any perceptible membranous lining

The bronchial intercellular passages are at first of a circular form and like the bronchial tubes do not communicate with many air cells but as they approach the surface of the lobule the number keeps increasing and at length these openings of communications are so numerous and so near together that the intercellular passage loses altogether its circular figure and becomes reduced to an

dilated as stated by Reisseisen but has about the same diameter as the passage of which it is the continuation (Fig 139)

The air cells which are situated close to the bronchial tubes or intercellular passages open into them by large circular apertures whilst those which are placed further from these passages communicate with them through the medium of other cells As these openings are not necessarily in a straight line the exact quantity of cells which communicate can not in this manner be determined but the number will depend upon the distance which intervenes between any given part of a bronchial passage and the surface of a lobule so that when a bronchial passage arrives nearest the surface it will be separated from it only by a terminal cell

The parenchyma of the lung according to Rainey is therefore largely made up of intercommunicating air cells which are destitute of an epithelial lining

HIPPOLYTE ROSSIGNOL (1815–70)

Having noted the fact that just beneath the pleura in sections cut from a blown up and dried lung there can be seen when examined with a low power lens numerous small cavities which are separated from each other by fine walls while in the thicker and more deeply situated portion of the section these cavities are arranged in groups which vary in number and are surrounded by thicker walls Rossignol goes on to say that he will continue the critical examination of the section before demonstrating one of the most important arrangements of the aerial apparatus

I have remarked that near the border of the section that is to say where it is the thinnest there exist only pulmonary alveoli adjacent to each other without marked traces of the large cavities which in reality enclose them in more or less numerous groups while in the thickest places these cavities are very visible This follows since the walls of these last diminish in thickness in proportion as they approach the surface of the lung and there end by being no longer differentiated from the alveolar walls which

seem to continue them In order to be convinced it suffices to observe the pulmonary section where these kinds of openings commence. One sees then evidently that here are the external sides of these alveolar groups, without having much more thickness than the other sides, and in place of stopping as these do at a certain height, they continue indefinitely in thickening themselves

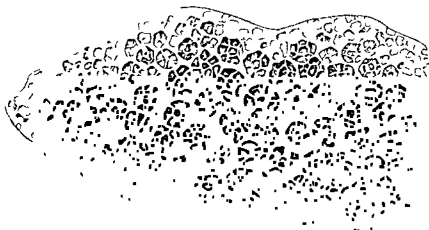


Fig 140—Thin section from the pleural surface of the lung of the cat At the borders of the section only isolated alveoli are seen, in the center, where it is somewhat thicker, the alveoli are enclosed in the infundibula, where they rise up from the bottom of them as so many terminal cells The spaces or walls which separate the infundibula are marked by depressions, irregular and more or less pronounced, which are the origin of many alveoli These last rest upon the external walls of the subpleural infundibula and are enclosed likewise in the infundibula, in the same manner as one observes when the section has a little more thickness than the one illustrated (After Rossignol)

more and more and in this manner constitute the great cavities (Fig 140)

"From where they arise they effect a polygonal form, but more nearly approach a circular form than the alveoli In proportion as they become deeper (in the lung) one observes that their orifices at the surface of the section become more and more round and contract considerably, so that they represent very well a hollow truncated cone or a kind of funnel whose large extremity should rest upon the pleura. To shorten the description and make it more intelligible, I will designate these cavities under the name of infundibula or funnels. . . . The infundibula or terminations of the bronchial ramifications constitute one of the most important parts in the minute structure of the lung No anatomist has noticed or even suspected the existence of them.

Each of these infundibula represents a small sac more or less conical in shape its internal surface partitioned off by numerous alveoli having but a single opening of communication with the external air It is on a small scale the representation or the exact reproduction of the reptilian lung and especially of that of the batrachians So that the human lung looked at from this point of view may be defined as the assemblage or concentration of innumerable small lungs like those of reptiles and bound together by means of a common bronchial tree (Fig 141)

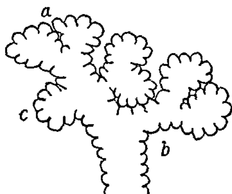


FIG 141 —Mode of termination of a bronchial branch in the lung of the dog The infundibula their tube of reunion the terminal alveoli and the parietal alveoli are shown a two neighboring infundibula united by the thinning of the wall which separates them b tube of union of the infundibula or the last but one bronchial division The infundibulum placed over the ramification indicates the manner in which the dilatations fill the intervals that the aerial canals leave between them c an infundibulum which opens separately into a bronchial tube In this aerial dilatation one seem to contain others smaller and of less height (After Rossignol s Fig 7)

I have made this lengthy abstract of Rossignol s essay because it contains the original description and figure of an infundibulum

JACOB MOLESCHOTT (1822–93)

Moleschott does not agree with Reissessen that the bronchial tubes terminate by rounded extremities nor with Willis that they terminate in cul-de sac with dilated extremities He supports the statement of Malpighi that not only are there vesicles on the extremities of the bronchial tubes but there are also vesicles which open into them along their lateral walls (Fig 142) Moleschott evidently saw longitudinal sections of bronchioli respiratorii or

to find any communication between neighboring vesicles except

that by which they were connected with the bronchial tube

scl

pre ... and, it seems to me, does not have as comprehensive an idea of the lung as Moleschott

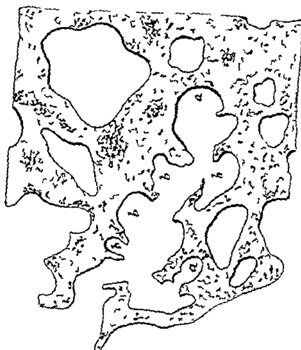


Fig 142 —*Section from the lung of a full term child* It shows a bronchiolus with which are connected parietal (b) and terminal (a) vesicles (Moleschott)

LOUIS MANDL (1812-81)

Mandl injected the lung with gelatin, when dry, he cut thin slices, moistened them with water and examined them under the microscope For the best results it was necessary to have longitudinal sections which included a terminal bronchus Such sections, he says, are somewhat difficult to obtain This studying of single sections which cut a bronchus longitudinally, explains many of the *misconceptions made by authors*

No single section tells the whole story, still, Mandl made several *observations which have stood the test of time* He said "*Lateral and terminal vesicles never communicate except through their common bronchus and never communicate with the intercellular*



Fig 143.—Thin section of a dried lung a terminal vesicle b lateral vesicles c transverse section of a bronchus or of a vessel d projecting wall of the vesicles (After Mandl Fig 2)

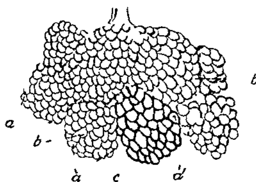


Fig 144.—From an injected lung of a newborn child a lobules b terminal and lateral vesicles c capillary vessels d three or four terminal vesicles viewed from above (After Mandl Fig 4)

connective tissue. Again, one often sees the wall of a lateral vesicle continuous for a certain distance into the interior of the terminal bronchus and thus form an isolated protuberance (Fig. 143). Had he made use of serial sections he would have understood the significance of this protuberance. Mandl found, on making colored injections, some lobules which press against each other, suspended from a common trunk and composed of a collection of vesicles, in a word, a structure analagous to a lobulated gland (Fig. 144).

ARIUS ADRIANI (?-?)

In his general description of the lung Adriani agrees with Rossignol. He accepts the name infundibulum introduced by Rossignol and so designates the final terminations of the bronchial tubes (Fig. 145). He also describes alveoli as being connected not only with the infundibula but also with the walls of the bronchial tubes just before they end in the infundibula; these alveoli open respectively into the infundibula or into the bronchial tubes. Each infundibulum has not inaptly been compared to a frog's lung in miniature.

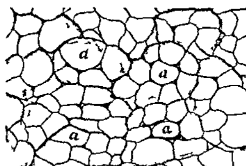


Fig. 145.—Pleural surface of the human lung, indicating the lobules in shaded outline and the air cells a, a. (After Adriani.)

Rossignol failed to find in normal lungs any communication between adjoining alveoli; when such communications were seen he considered them pathological. On the other hand Adriani thought differently, for he says: "It becomes a most important question whether the neighboring alveoli, according to Rossignol, only communicate with each other by means of the branch with which they are connected, or whether they also communicate by other lateral openings. We consider the opinion of Rossignol without doubt false, since we have seen most minute round and elliptical openings in other lungs, and most clearly in those of Cervus elephus (red deer), by means of which a communication is established between neighboring infundibula." This is the first description of alveolar pores, and from the time of Adriani until the present it has proved an interesting topic for study or discussion (see page 65).

ERNESTUS SCHULTZ (?-?)

Accepting the description of Sommering Schultz says that the subdivision of the bronchi within the lung is arboreal rather than dichotomous as stated by Krause and others

If a complete cross section that is very thin and of uniform thickness be cut from a dried lung and examined under the micro

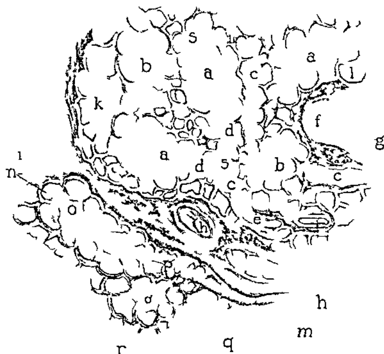


Fig 146—Thin section from a lung which was blown up with air and dried Schultz had a very comprehensive idea of lung structure For description of figures see text

scope we see an irregular network (Fig 146) These meshes form a series of openings The larger are elliptical (a) and the smaller ones are round (1) or have rounded angles From the edges of the larger openings denticulated processes (s) curve in toward the interior of the opening where as often happens large openings have a common wall these processes are given off from either side in a more or less alternate manner Furthermore these large elliptical

connective tissue' Again, "one often sees the wall of a lateral vesicle continuous for a certain distance into the interior of the terminal bronchus and thus form an isolated protuberance' (Fig 143) Had he made use of serial sections he would have understood the significance of this protuberance Mandl found, on making colored injections 'some lobules which press against each other suspended from a common trunk and composed of a collection of vesicles in a word a structure analogous to a lobulated gland' (Fig 144)

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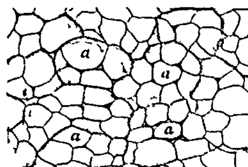


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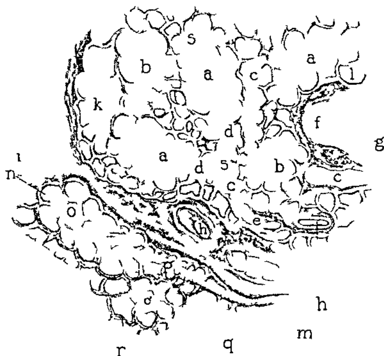


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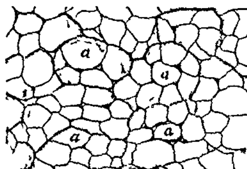


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infundibulum is surrounded with a layer of connective tissue, on the contrary, he found that there are polygonal areas, which include groups of infundibula with their accompanying bronchioles *and blood vessels, that are surrounded by connective tissue* These groups, into which a branch of the bronchus enters, vary in size and collectively form the lobules

RUDOLPH ALBERT KOLLIKER (1817–1905)

After stating that the finest divisions of the bronchi terminate in a group of air cells rather than in a single vesicle, as stated by Rossignol, and that this group of air cells constitutes a lobule, Kolliker says "there is no occasion whatever to designate them under any other name, as was done by Rossignol, who calls them *infundibula*"

In the child these lobules (primary lobules) are more distinct than in the adult In the adult these lobules vary from one-fourth of a line to one line in size, but are so closely blended that, even on the surface of the lung, their outlines can with difficulty be made out In the interior of the lung they have a more homogeneous character, resembling the liver On the other hand, the secondary lobules, one-fourth of an inch to one inch in size (lobules of authors) are most clearly marked out, the more so because the boundary lines are marked out by lines of pigment which in the course of time has been deposited in the interlobular connective tissue Collectively these lobules (secondary lobules) form the lobes of the lung (Fig 147)



FIG 147—Two small pulmonary lobules with the air cells b b and the finest bronchial twigs c c which also possess air cells From a newborn child Half schematic (From Kölliker)

ROBERT BENTLEY TODD (1809–60)
and
WILLIAM BOWMAN (1816–92)

Their use of the term "lobule" is somewhat confused, for they first describe a lobule as being mapped "out of the pulmonary substance into small polyhedral masses separated by areolar tissue and

openings have a narrower end and not rarely it passes on into a still narrower passage of greater length (c), whose edges have the same nature as the edges of the larger openings and, like them, send out denticulate processes (s′) Occasionally there may be seen *openings that are wider or narrower, round (f), or more protracted* in length (c′), the latter often lying next to the former All these openings are surrounded by heavier walls which vary in thickness with the diameter of the opening The surface of these openings *turned toward the lumen is smooth* Some of the larger openings contain cartilaginous plates (g) Other openings (h) are seen, being larger or smaller in size and surrounded by a band which varies *in thickness marked with irregular furrows and tinged yellow white* in color, and never communicate with the openings surrounded by the thinner outlines

Finally, there are seen everywhere tracts, irregular in form and, size (i), which correspond to the tissue surrounding the openings just described Enclosed in these tracts there are areas of pigmentation (m) of greater or less size More frequently, when sections are cut, *lamellae of uneven thickness are obtained, which* give modifications of the miscroscopic image just described The large openings with thin walls (a, b) seem to be missing, but the smaller round ones appear in great numbers and situated close to one another (n) Moreover, the lumina of these openings appear to be full of a transparent, glass like membrane When the focus of the microscope is moved up and down, this membrane, which *closes the small round openings, appears in some of the openings to be curved towards the observer, in others away from the observer* (In other words, Schultz saw the thin walls of the alveoli sometimes from above, sometimes from below)

In his summing up, *Schultz recognizes the difference between* sections of blood vessels (h) and bronchi (f) He also recognizes that the large hollow spaces (a) are continuous with a narrow canal (d) which has the same characteristic walls The large openings (a) he calls as did Rossignol and Adriani, infundibula, the smaller *openings, alveoli The alveoli situated on the* blind end of the

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fundibula and of the petioli, have no direct connection with one another but only through a common hollow body, of which they are, as it were parts ' In this *statement Schultz directly opposes* Adriani who had said that there were direct communications (pores) between adjoining infundibula

Schultz does not agree with Huschke when he says that each

having a very irregular shape" They here describe what are now called *secondary lobules* but they go on to say Nevertheless it seems certain that *each terminal twig of the bronchus is in relation with only its own proper set of air cells and that such sets of cells do not communicate except through the medium of the bronchia* In this sense lobules exist everywhere even when not isolated by areolar tissue and in this sense we shall use the term as conveniently designating that series of air cells associated by dependence on a single terminal air tube'* They here define the air spaces forming a *primary* lobule Todd and Bowman do not give an original diagram of the arrangement of the air spaces but they do give so concise a definition of what constitutes a *secondary* lobule and what constitutes a *primary* lobule that I quote in full

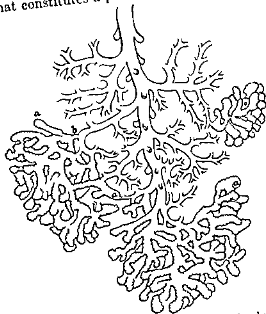


FIG 150—Diagram of portions of the human lung imperfectly injected with wax exhibiting the mode in which the intercellular passages a a a spring from the ultimate bronchi b b These are smooth walled those alveolated (After Williams)

THOMAS WILLIAMS (1819–65)

In the supplementary volume of the *Cyclopaedia of Anatomy and Physiology* Williams gives a résumé of previous work and adds some

* Italics mine W S M

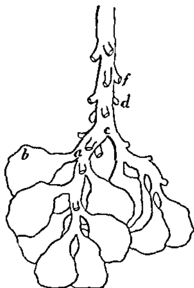


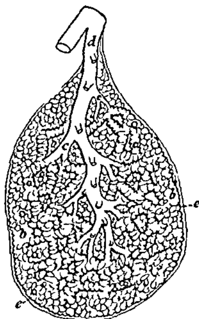
FIG 148—A group of lobules loosened from their mutual attachments, indicating the mode in which each lobule (b) receives a single bronchial tube (a) (After Williams)

At c is represented the dichotomous manner in which the primary and secondary orders divide, at c, d, and f, is shown the irregular arborescent method in which the terminal lobular bronchi project from every side and point of the circumference of the secondary bronchial tubes

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FIG 149—An imaginary section of a lobule of the human lung carried parallel with the plane of distribution of the chief interlobular divisions of the bronchi The latter are observed to multiply both on the dichotomous and arborescent plan (After Williams)

c, c denote the smallest of the true bronchi which contrast by their smooth walls the alveolated intercellular passages a, a, a The latter exceed the extreme bronchules slightly in diameter Unlike these bronchules (c) which never inosculate, the intercellular passages (a) ramify in every direction and at every plane, and frequently open into one another, establishing thus a free communication for the air between all parts of the lobule b, b b indicate the ultimate air cells of the lungs They correspond in size with the alveoli (themselves true cells) on the walls of the intercellular passages e, e, bottom of the subpleural or most superficial air cells



animals, as the cat, the subdivision of the lobes into lobules does not exist, whilst in others, as the calf, it is carried on to a very great extent, the lobules being very numerous, and some of them very small"

In another place he says "Each secondary lobule of a lobe has its separate bronchial tube, and the number of divisions which take place within it varies with its size in general the subdivisions are few" The last division of the bronchial tree he calls the "*terminal bronchial tube*," sometimes the "*ultimate bronchial tube*" Connected with each terminal bronchial tube are somewhat elongated cavities to which he gives the name "*air-sac*" These are arranged in groups All the air sacs communicate directly with the dilated end of the ultimate bronchial tube, which forms the *point de reunion* (Fig 151) Each air-sac communicates with the ultimate bronchial tube by means of a circular opening More than one air-sac may terminate at one of these openings "The air sacs connected with one bronchial termination do not communicate with those of another each set of air sacs is therefore a little lobule, or 'lobulette,' which, in fact represents the entire arrangement of the lung and is a lung in miniature" In other words, the lobulette of Waters represents what is now termed the *primary lobule* (Fig 152)

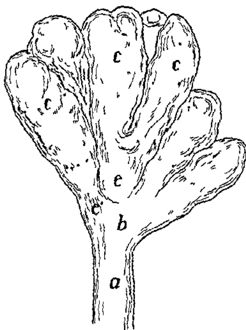


Fig 152—Terminal bronchial tube with a group of air sacs (sacculi alveolares) or lobulette connected with it (human) a the terminal bronchial tube b the dilated extremity of the terminal bronchial tube c c c individual air-sacs At e e are seen the openings of other sacs which lie beneath those which are exposed six sacs are seen converging to the common centre The markings in the air sacs denote the boundaries of the alveoli (After Waters)

individual observations 'The proper pulmonary tissue (Fig 148) begins where the bronchial tubes end' Williams' diagram apparently
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for his lobule is made up of a series of branching and intercommunicating passages which terminate in the ultimate air cells of the lung

'Those cells which communicate directly with the bronchial tubes and intercellular passages open into them by large circular

cells extending from it to the surface of the lobule" (Fig 150)

A T HOUGHTON WATERS (1826–1912)

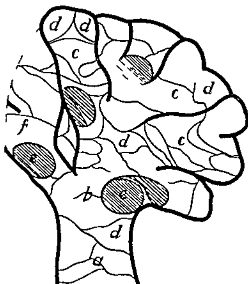


Fig 151 —Ultimate bronchial tube with its air sacs (sacculi alveolares) a ultimate bronchial tube b its dilated end the *point de reunion* of all the air sacs c c c air sacs d d alveoli e e openings leading to other air sacs f part of the wall of two air sacs which are cut off From the lung of a cat (After Waters)

Under the caption 'Subdivision of the lobes of the lung into lobules' Waters says 'Each lobe of the lung is an agglomeration of a number of small lobules, which represent the organ on a small scale The lobules are found in every part of the lung They are arranged almost in a similar manner to grapes on a branch, for each is found in connection with a bronchial tube which may be considered as its stalk Each lobule is enclosed in a sheath which consists of condensed areolar tissue in which a large amount of the yellow elastic element is found This sheath forms a perfect septum between the lobules and isolates them from each other'

Waters here describes what is now termed a secondary lobule and his description differs but little from that of Willis 'In some

animals as the cat the subdivision of the lobes into lobules does not exist whilst in others as the calf it is carried on to a very great extent the lobules being very numerous and some of them very small

In another place he says Each secondary lobule of a lobe has its separate bronchial tube and the number of divisions which take place within it varies with its size in general the subdivisions are few The last division of the bronchial tree he calls the *terminal bronchial tube* sometimes the *ultimate bronchial tube* Connected with each terminal bronchial tube are somewhat elongated cavities to which he gives the name *air sac* These are arranged in groups All the air sacs communicate directly with the dilated end of the ultimate bronchial tube which forms the *point de reunion* (Fig 151) Each air sac communicates with the ultimate bronchial tube by means of a circular opening More than one air sac may terminate at one of these openings

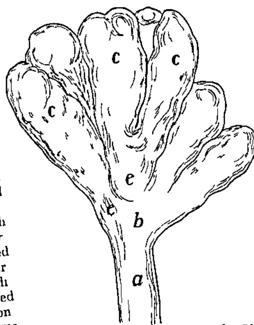


Fig 152 —Terminal bronchial tube with a group of air sacs (sacculi alveolares) or lobu ... the termi ... v of ... it (human) a ... air-sacs At e e ... beneath those wi ... sacs which lie beneath those ... sacs are seen converging to the common centre The markings in the air sacs denote the boundaries of the alveoli (After Waters)

The air sacs connected with one bronchial termination do not communicate with those of another each set of air sacs is therefore a little lobule or lobulette which in fact represents the entire arrangement of the lung and is a lung in miniature In other words the lobulette of Waters represents what is now termed the *primary lob le* (Fig 152)

JOSEPH GERLACH (1820–96)

If a section from a blown up and dried lung be examined under the microscope numerous round or oval openings are seen which are separated from each other by narrow bands of a fibrous substance These openings correspond to sections of bladder like bodies into which the last of the little branches of the bronchi which ramify throughout the lung open Besides these openings there are tube like bands which are half the size of the average opening These tubes are nothing more than the final branching of the bronchi Each individual branch corresponds to a primary

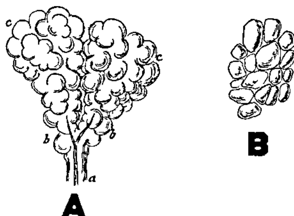


Fig 153—A Two primary lobules of the lung from a newborn child with its bronchiolus and end branches of the pulmonary artery a bronchiolus b lateral c terminal alveoli ×50

B Base of a lobule of the lung situated immediately beneath the pleura From the lung of a cat ×50

lobule of the lung which has the form of a short cone whose point in the form of a handle represents the shorter or longer bronchiolus The bases of these primary lobules are seen clearly marked out only on the surface of a child s lung since the larger polygonal areas which are seen on the surface of the adult lung marked out by more or less regularly distributed pigment correspond to the *secondary lobules which are formed from several primary lobules* The smallest bronchi which Gerlach observed had a diameter of 0 1125 mm and the base of a primary lobule measured from 0 45 mm to 0 675 mm while the base of a secondary lobule measured from 1 8 mm to 2 7 mm Gerlach s figure of the primary lobule is practically the same as that of Kolliker with the addition of the pulmonary artery (Fig 153)

FRANZ EILHARD SCHULZE (1840-1921)

Each lung is supplied with a single bronchus which breaks up into a series of dichotomous branches as soon as it has penetrated into the substance of the lung These branches pursue a straight course until they reach a position near the surface of the lung Each of these branches gives off laterally, in a spiral manner, still smaller branches which, in turn, give off lateral branches that break up

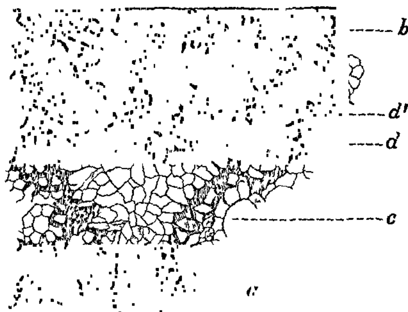


Fig 154—Section of a cat's lung filled and hardened with alcohol a, bronchiolus b, infundibulum c transverse section of an alveolar passage, d, d', longitudinal section of an alveolar passage (After Schulze)

into the terminal branches These terminal branches, which have a diameter of 0 3 to 0 2 mm, end in the respiratory cavities These cavities, which also consist of round passages, undergo repeated subdivisions and finally end in funnel-shaped spaces—the infundibula These passages do not, like the bronchi, possess unbroken walls but have smaller cavities opening into them—the alveoli, which are closely set about them

Although Schulze recognized that more than one subdivision of the bronchial tree had alveoli along its walls, he considered them as one continuous passage and gave to it the name *alveolargang* (Fig 154)

Now for the first time a name is given to that subdivision of the bronchial tree which possesses alveoli and is situated between the last division of the bronchial tree that has smooth walls and an infundibulum

WILLIAM TURNER (1832-1916)

The diagram of Turner corresponds to the primary lobule of Kolliker cut open longitudinally (Fig 155) This consists of a

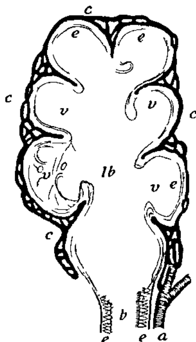


Fig 155 — Semi diagrammatic longitudinal section through an infundibulum b terminal bronchial tube lb lobular passage vv air vesicles in v the nucleated elastic membranous wall of a vesicle is shown a pulmonary artery c c pulmonary capillaries e ciliated epithelium e e tesselated epithelium lining air cells (After Turner)

terminal bronchial tube (b) which has dilated into an *infundibulum* the lumen of which he calls the *lobular* or *alveolar passage* (lb) Each lobular passage dilated both laterally and terminally into *alveoli* or *air vesicles* (v) The air vesicles belonging to an individual infundibulum are separated from each other by septa they do not communicate with each other but only with the lobular passage The air vesicles of one infundibulum do not communicate with those of adjoining infundibula but are separated from them by a thin layer of connective tissue and blood capillaries

GEORG EDUARD RINDFLEISCH (1836-1908)

Rindfleisch studied the structure of the lung from corrosion preparations with the following results

In the lobule studied (secondary lobule) a bronchus (sublobular bronchus of Sappey) enters the lobule and gives off seven bronchioli, each of which in turn divides into two very short bronchioli These small bronchioli spread out into an arborization of from three to five alveolengange which collectively form a "lung acinus" This acinus is, according to Rindfleisch, a much more constant unit of lung structure than the lobule The lobule is not constant in size, for two lung acini may constitute a lobule, on the other hand, there are lobules in which there are 20 to 30 acini From a pathological stand point, the lobule is the more important since it is enclosed by connective tissue and contains the ramifications of the blood vessels Moreover, the interlobular connective tissue helps to restrict the spread of emboli, infarcts, abscesses, etc Although he does not in his diagram indicate infundibula and alveoli in other places Rindfleisch speaks of infundibula and alveoli without mentioning their relation to his acinus (Fig 156)

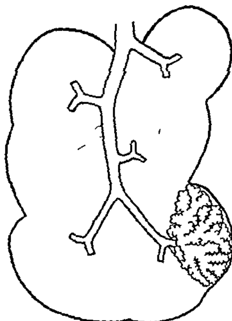


Fig 156 —Lobule of the Lung (Rindfleisch)

Rindfleisch seems to have been the one who established the term 'acinus' in descriptions of the finer structure of the lung for from his time until the present it is still in use

JEAN MARTIN CHARCOT (1825–93)

Charcot bases his description of the air spaces in the lung on the lobule as described by Rindfleisch and called by him a primary lobule The bronchus which enters the lobule he terms the *sublobular bronchus* within the lobule this gives rise to the *intralobular bronchi* and the short branches into which the intralobular bronchus divides he calls *terminal bronchioles* since they represent the end of the bronchial system The orifices of the terminal bron

chioles which face the surface open into a system of canals called by Charcot *canaliculi* and these collectively form his secondary lobules which he describes as being separated from adjoining lobules by a lamella of connective tissue which he says is very distinct in young children less so in the adult but can be recognized upon the base of the lobules situated just beneath the pleura

Here we find primary and secondary lobules confused for the true primary lobules are not separated from each other by connective tissue even in the new born child

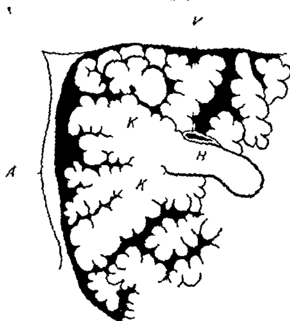


FIG 157 —Pulmonary acinus of a new born child injected with wax H bronchiole V branch of the pulmonary artery KK alveolar conduit A intralobular space (Charcot)

Charcot thinks that his term secondary lobule is open to objections so he proposes to substitute for it the name used by Rindfleisch *pulmonary acinus* for some call secondary lobules what others call *primary lobules* there are indeed those who apply the term *secondary lobule* to only a part of the entire acinu

Charcot says his pulmonary acinus corresponds exactly with the system of the alveolengange (alveolar passages) of Schulze and with the lobulettes of Waters but if Charcot s figure of a pulmonary acinus (Fig 157) be studied carefully it will appear to correspond with the lobulette of Waters (see Waters Figure 151) more closely than with that of Schulze Charcot criticizes Waters

term "lobulette," which he says is inconvenient since it belongs to no language in spite of its French sound

Attention is called to the dilated end of the terminal bronchiole called, by Waters "point of re-union," by Charcot, "vestibule" It was this use of the term "vestibule" that led me to drop it from my original description

Leading out from this vestibule there is a series of *conduits alveolares* or alveolar passages (alveolengänge of Schulze) which terminate in a funnel-shaped cavity, the *infundibulum* of Rossignol Extending from the vestibule through the center of the conduit



FIG 158 —From the lung of a sheep embryo 250 mm long a bronchiolus d alveolar passages (Stieda) ×80

there is a free space, which gives access to the lateral alveoli which are upon the walls of the conduit and bear the name *parietal alveoli* Charcot compares this disposition of the air spaces to the long corridors of a prison into which the laterally situated cells open Later he compares this arrangement to a Roman house, in which the central space corresponds to the *impluvium* and the alveoli to the *cubicula*

Not only are there terminal infundibula, but there are also *lateral infundibula* which communicate with the conduits

Finally, Charcot mentions that there can be seen by high amplification, interalveolar spaces, but does not give an extended account of them

LUDWIG STIEDA (1837–1918)

"The bronchi, after they have divided and branched frequently pass finally over into branches and irregularly pouched canals, which end blindly—these are the alveolengange of Schulze" (Fig

158) The smallest bronchioli from which these canals arise do not have smooth walls, but they have numerous half round or spherical pouches—alveoli—placed close to one another, projecting from the surface

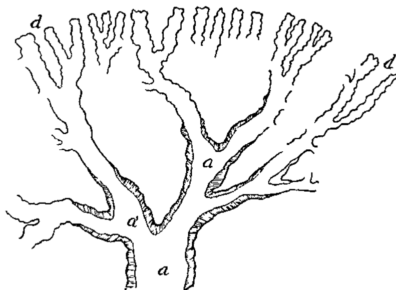


Fig 159 —From the lung of a mouse Showing transition of small bronchial branches into bronchioli (a', a') and into alveolar passages (d) (Stieda) ×60

The canals do not end blindly with funnel shaped expansions, and Stieda agrees with Henle that the term infundibulum should be dropped (Fig 159)

E LAGUESSE (1861-?)

The pulmonary parenchyma, or proper tissue of the lung, can be separated into lobules ' Primary or simple lobules are defined by Laguesse as those polyhedral areas which are marked out on the surface of the lung by lines more or less pigmented, are bounded within the lung by connective tissue septa, and are of a more or less pyramidal shape These areas are usually called secondary lobules, but Laguesse considers them primary lobules

Into these lobules enters a sub-lobular bronchus which continues through the middle of the lobule until it has reached a point near its center, where it divides into two principal branches, intralobular bronchi During its course through the lobule it gives off

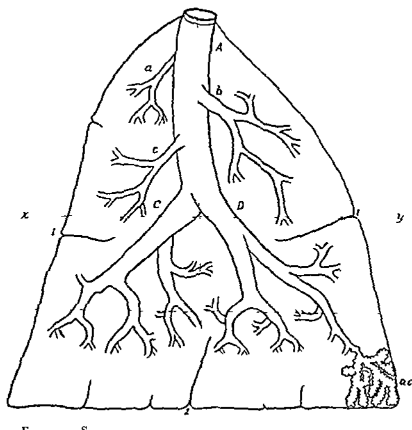
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bronchioles or *bronchioles acineuses*

Each terminal bronchiole (bronchiole acineuse) ends in a dense cluster of short wide branches bearing numerous alveoli Each cluster forms an acinus which corresponds to the acinus of Rind



fleisch and Charcot but is much more complicated than that of Schulze

The *bronchiole acineuse* has scattered alveoli along its walls Presently this bronchiole enlarges its walls become thinner and alveoli appear on practically the entire circumference of the bronchiole it is now called after the nomenclature of Schulze an alveolar canal (alveolargang) The e alveolar canals continue to divide several times and eventually end in a simple *cul de sac*

Sometimes these alveolar canals which abut against the pleura terminate in a club-shaped dilatation (Fig 160)

The passage of the bronchiole into an alveolar duct is not abrupt and the last bronchial branches possess transitional characteristics which are found not only upon the *bronchiole acineuse* but often on its preceding branch These transitional bronchioles bear alveoli

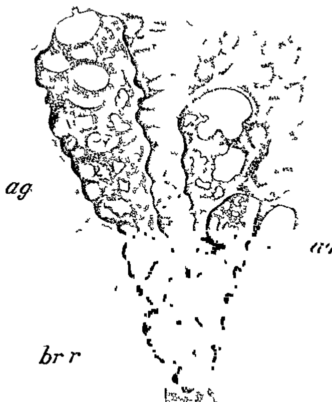


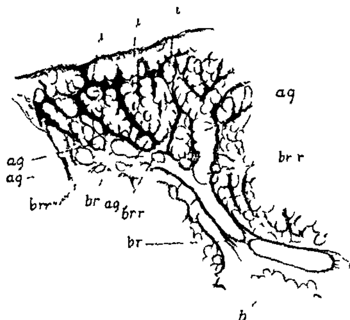
Fig 161 —Bronchiolus respiratorius br r and two alveolengange ag from the dog (Kolliker) ×85

which are smaller than those of the acinus they have been rightly termed by Kolliker *bronchioli respiratorii* but Laguesse thinks that Kolliker is wrong when he includes in this division of the bronchial tree those bronchioles which do not possess alveoli and are not lined with a mixed epithelium consisting of cuboidal and simple respiratory epithelium

RUDOLPH ALBERT KOLLIKER (1817-1905)

where cartilages and glands disappeared from the bronchi the types of epithelium and the finer divisions of the bronchial tree In this section only the subdivisions of the bronchial tree will be considered the others having already been discussed in preceding sections

When the bronchioli have been reduced to a diameter of one mil



limeter a change in their structure takes place They no longer maintain a cylindrical outline but with increasing numbers, alveoli appear on their walls On account of this change in the character of the bronchioli Kolliker gives to this subdivision the name respiratory bronchioles (*bronchioli respiratorii*) After a longer or shorter course they are continued as the alveolengange of Schulze (*ducti alveolares*) and eventually end in an *infundibulum*

a term which he had formerly discarded as incorrect We now have the elongated alveolengange of Schulze divided into two distinct portions *bronchioli respiratorii* and *ductuli alveolares* and a new conception of bronchial architecture (Fig 161) Whatever criticism may be brought against his description of the epithelium belonging to the bronchioli respiratorii none can be brought against his recognition of this new subdivision of the bronchial tree

The order of the finer divisions of the bronchial tree are with *this new subdivision bronchioli bronchioli respiratorii ductuli alveolares infundibula* this latter term to be eventually replaced by *sacculi alveolares* (Fig 162)

HENRI BERDAL (1864-?)

According to the description of Rindfleisch and of Charcot the sublobular bronchus enters the lobule and follows its axis from the summit to the vicinity of the base where it terminates in a bifurcation In this course the *sublobular bronchus* having become the *intralobular bronchus* gives rise to alternating lateral bronchi *intralobular bronchioles* of the second order which can divide a certain number of times and finally terminate by very short conduits designated under the name of *acinal bronchi* Each of these last ramifications leads into a group of alveoli whose ensemble constitutes a pulmonary acinus (Fig 163)

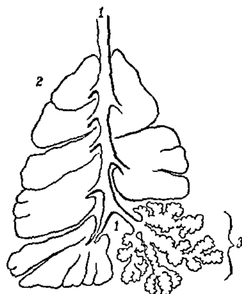


Fig 163 —Scheme to show the configuration of the pulmonary lobule 1 pre lobular bronchus 2 intra lobular bronchus 1 acinus bronchus 3 acinus of the lung (Berdal)

In studying the course of the intralobular bronchial tube we have seen that the ultimate division was represented by a terminal conduit the acinal bronchus which marks the boundary between the bronchial system and the alveolar system This bronchial tube after a very short course contracts to spread abruptly bell shaped to form a kind of funnel to which the name of *vestibule* has been given From this funnel go out

three four or five conduits the *alveolar conduits* which turn away from each other at very acute angles in a manner as to represent a kind of bouquet dominated by the acinal bronchus, and whose ensemble constitutes a *pulmonary acinus* which we can compare with the pulmonary lobule itself In fact the acinus has the form of a pyramid whose summit is suspended from a sort of pedicule represented by the acinal bronchus and whose base faces the periphery (Fig 164) In its general appearance the acinus differs

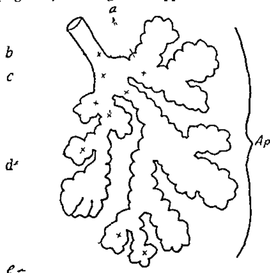


FIG 164—Scheme of pulmonary acinus a alveolar conduits b acinal bronchus c vestibule d lateral infundibula e terminal infundibula Ap pulmonary acinus (Berdal)

little from that of the lobule but is much smaller measuring only about one millimeter in diameter In the same manner as the lobule the acinus is separated from the neighboring acini by a connective tissue capsule a great deal less marked it is true but distinct enough to assure a relative independence to the acinus This peri acinal connective tissue abundant enough in the child is reduced considerably in the adult in the same manner as the perilobular connective tissue will disappear in the aged at the point where the lobules come in contact Finally in the same manner as the sub lobular bronchus dominates in the lobule an area clearly circum scribed and enjoying an almost complete independence so the acinus bronchus supports a small alveolar system well defined as to boundary from the functional point of view (Joffroy)

a term which he had formerly discarded as incorrect We now have the elongated alveolengange of Schulze divided into two distinct portions, *bronchioli respiratorii* and *ductuli alveolares*, and a new conception of bronchial architecture (Fig 161) Whatever criticism may be brought against his description of the epithelium belonging to the bronchioli respiratorii, none can be brought against his recognition of this new subdivision of the bronchial tree

The order of the finer divisions of the bronchial tree are, with this new subdivision *bronchioli, bronchioli respiratorii, ductuli alveolares infundibula* this latter term to be eventually replaced by *sacculi alveolares* (Fig 162)

HENRI BERDAL (1864-?)

According to the description of Rindfleisch and of Charcot, the sublobular bronchus enters the lobule and follows its axis from the summit to the vicinity of the base where it terminates in a bifurcation In this course the *sublobular bronchus*, having become the *intralobular bronchus* gives rise to alternating lateral bronchi *intralobular bronchioles* of the second order which can divide a certain number of times and finally terminate by very short conduits designated under the name of *acinal bronchi* Each of these last ramifications leads into a group of alveoli whose ensemble constitutes a pulmonary acinus (Fig 163)

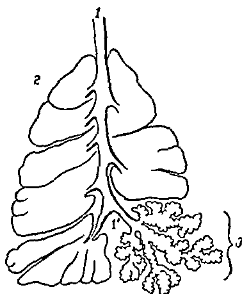


Fig 163 —Scheme to show the configuration of the pulmonary lobule 1 pre lobular bronchus 2 intra lobular bronchus 1' acinus bronchus 3 acinus of the lung (Berdal)

In studying the course of the intralobular bronchial tube we have seen that the ultimate division was represented by a terminal conduit, the acinal bronchus which marks the boundary between the bronchial system and the alveolar system This bronchial tube, after a very short course, contracts to spread abruptly, bell shaped, to form a kind of funnel to which the name of *vestibule* has been given From this funnel go out

three four or five conduits the *alveolar conduits* which turn away from each other at very acute angles in a manner as to represent a kind of bouquet dominated by the acinal bronchus and whose ensemble constitutes a *pulmonary acinus* which we can compare with the pulmonary lobule itself In fact the acinus has the form of a pyramid whose summit is suspended from a sort of pedicule represented by the acinal bronchus and whose base faces the periphery (Fig 164) In its general appearance the acinus differs

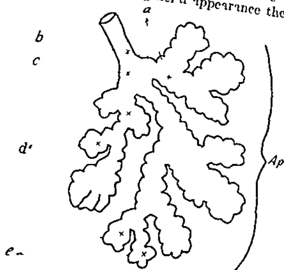


Fig 164—Scheme of pulmonary acinus a alveolar cond its b acinal bronchus c vestibule d lateral infundibula e terminal infundibula Ap pulmonary acinus (Berdal)

little from that of the lobule but is much smaller measuring only about one millimeter in diameter In the same manner as the lobule the acinus is separated from the neighboring acini by a connective tissue capsule a great deal less marked it is true but distinct enough to assure a relative independence to the acinus This periacinal connective tissue abundant enough in the child is reduced considerably in the adult in the same manner as the perilobular connective tissue will disappear in the aged at the point where the lobules come in contact Finally in the same manner as the sublobular bronchus dominates in the lobule an area clearly circumscribed and enjoying an almost complete independence so the acinus bronchus supports a small alveolar system well defined as to boundary from the functional point of view (Joffroy)

Let us now return to the description of the different parts which enter into the composition of the acinus The acinus bronchus and the vestibule are completely *smooth* on the contrary, the alveolar conduits present *embossed walls* covered with depressions separated by delicate walls which are described under the name of *pulmonary alveoli* Following the well known comparison of Charcot, the alveoli open into the alveolar conduits in the manner of cells in the central corridor of a prison

Communications of the alveoli depending upon the same alveolar *conduit are very easily acquired, for they* are separated only by rudimentary walls, on the contrary, the alveoli of a conduit do not communicate with the alveoli of the neighboring conduit

Besides the simple alveoli, the walls of the alveolar conduits *present larger depressions that terminate in a cul de sac,* which is also covered with alveoli These groups of alveoli are known under the name of *infundibula* and, according as they occupy the terminal extremity or the walls of the alveolar conduits they are called *terminal* or *parietal infundibula*

After having made the analysis of the lung in going from the lobule to the acinus and to the alveoli, it is fitting to follow the inverse course and to reconstruct this organ by going from the alveoli towards the lobule In proceeding thus we see that

a) Each alveolar conduit possesses under its dependence a certain number of simple or compound alveoli (infundibula) and forms the primitive lobule of the lung (Sappey)

b) The primitive lobules to the number of four or five form a cluster suspended from the acinus bronchus a pulmonary acinus

c) Finally, the acini reunite to the number of fifteen or eighteen to constitute the pulmonary lobule (secondary lobule) We have already indicated how the lobules by their reunion come to form the lobes of the lung

I have given quite fully a free translation of Berdal's description, because he gives so complete an account of the structure of the lung from the standpoint of the French histologists

A NICOLAS (?-?)

The lung can be resolved into a large number of independent segments termed lobules When the bronchi through subdivision have attained a calibre which usually *does not exceed 1 mm*, they penetrate into the lobules and are termed *intralobular* bronchi Each intralobular bronchus continues to divide and gives origin to from ten to fourteen small branches—the *terminal bronchioles* Up *to this point* the bronchial canals are regularly cylindrical, but from this point small hemispherical eminences appear, at first isolated

and less numerous, then more and more abundant until finally they are so numerous that they abut against each other These eminences correspond to small pockets in the wall of the bronchiole which communicate freely with the lumen of the bronchiole they constitute the alveoli and give to this part of the bronchial tree the name *bronchiolus respiratorius*

After a longer or shorter course each terminal respiratory bronchiole dilates into a small cavity or *vestibule* from which from three to six *alveolar conduits* arise These may remain undivided or they may subdivide several times but all eventually terminate in a

form aspect

Nicolas sums up the successive tracts through which the air passes to reach the bottom of the pulmonary apparatus where the

alveoli are found on the last three segments and a portion of the terminal bronchiole Although Nicolas makes free use of my diagrams and reconstruction from the lung of the dog his description is based largely on corrosion preparations which show how indefinite and practically useless such preparations are for studying the minute structure of the lung

H LOESCHCKE (1882-?)

Loeschcke illustrates by means of a corrosion an isolated acinus or *arbor alveolaris* as named by F E Schulze The stem of the cluster is formed by a *bronchiolus verus terminalis* which divides dichotomously in two *bronchioli respiratorii* from which go out alveolengange of one two and sometimes three orders and end in a blind sac the *sacculus alveolaris* on the surface of the acinus (Fig 165)



Fig 165 —Isolated acinus from the human lung Injected with Wood's metal Showing the branching of an end bronchus within the acinus (After Loeschcke) ×6

His figure is one of the best we have of a corrosion preparation but it does not show the structure of the lung correctly No method of investigating the lung gives so varied and erroneous an idea of its structure

Fig 166 —Reconstruction of an acinus from the human lung, by A. Vierling, and reproduced in colors by Braus Some portions are very cleverly executed, but in the main it is erroneous, especially in the arrangement of the finer air spaces

HERMANN BRAUS (1867-?)

Of the modern schemes of lung structure, that of Braus deserves special mention. It has many excellent features. His arrangement of the structures connected with one of the smaller bronchi is, in the main, correct, and they are displayed in a skilful manner, but his outline of the air spaces is far from accurate—the spaces which he designates as "atria" are sadly misplaced (Fig. 166).

The unit of construction according to Braus is an acinus. He reproduces the figure of Loeschcke (Fig. 165) to illustrate an acinus. From twelve to eighteen acini form a lobule. Each lobule is surrounded by an interlobular septum. In other words, the lobule of Braus corresponds to a secondary lobule.

Résumé

It must be borne in mind that the preceding sketch only deals with the arrangement of the air spaces. From the various schemes presented there are, after all, but few that have exerted a permanent influence, or made a place for themselves in the literature.

It was due to Malpighi that the blood vessels were separated from the air spaces and each system recognized as an independent system. T. Willis described independent secondary lobules attached to small branches of the trachea which subdivided within the secondary lobules into numerous finer branches that terminated in minute bladders which did not communicate with each other as did the vesicles of Malpighi.

Rossignol described each of the finer bronchial ramifications as ending in a funnel-shaped cavity which he called an *infundibulum*, a term which is still used in modern descriptions of lung structure.

Adriani introduced a new idea in lung structure when he stated that, while the wide open communications between adjoining alveoli described by many of the older authors did not exist, minute openings did exist in the walls of the normal alveoli. These minute openings are now known as *alveolar pores*, and the question as to their being normal openings is still being discussed (see page 65 et seq.).

In 1852 Kölliker differentiated between primary and secondary lobules, the latter being marked out by connective tissue in which pigment was usually deposited. Kölliker's diagram of a primary lobule was extensively copied by later investigators.

Waters introduced the terms *terminal bronchus* and *air sac*, these terms are still used by many authors. The group of air sacs connected with a terminal bronchus formed his lobulette. Schulze made a valuable contribution when he gave, for the first time, a

name, *alveolargang* (alveolar passage), to that subdivision of the bronchial tree which had alveoli opening out from its lumen and terminated in what, at that time, was called an infundibulum

Rindfleisch introduced the term *acinus* for the group of three to five alveolengange which were connected with the final sub division of the bronchial tree The acinus is considered the unit of lung structure by many authors

Kolliker in 1881 subdivided the long alveolargang of Schulze into a proximal portion, the *bronchiolus respiratorius* (respiratory bronchiole), and a distal portion, for which he retained the term *alveolargang* originally given by Schulze to the entire length

Grethmann in 1935 returned to the old idea that sections passing through as many air spaces connected with one another as possible, explained the structure of the lung He deprecated the construction of models, saying that they were unhandy "and liable to breakage," and "available only to a very restricted number of those interested" He advocated the use of "ideal longitudinal serial sections, that is, sections cut in the longitudinal plane of the terminal bronchial endings"

Chapter XII

THE ACINUS

It is quite evident, from the various schemes of the lung presented in Chapter XI, that the idea of Rossignol that the problem of the texture of the lung is bound up in the lobule, has been superseded by a theory that it is centered in the acinus The unit of construction is *not*, however, the acinus, *it is the lobule*

It has also been shown that there has been and still is, confusion as to what constitutes a primary lobule and what constitutes a secondary lobule Originally primary lobules were defined as the group of air spaces connected with the final divisions of the bronchial tree, while secondary lobules were made up of a variable number of primary lobules, the ensemble being separated from adjoining secondary lobules by connective tissue septa which in some instances, were highly pigmented

The primary lobule has been described in detail in Chapters IV, V, VI, and VIII It now remains to describe a secondary lobule In Chapter XI outline sketches of a secondary lobule have been given by Rindfleisch and Laguesse, but I have found no actual tracing of a secondary lobule in the literature on the lung

In Figure 167 a tracing of a secondary lobule taken 55 mm below the pleura of the human lung will be found The lobule is surrounded by a layer of connective tissue which serves to separate it from adjoining secondary lobules On the upper left a portion of a section of a bronchus with a plate of cartilage in its wall is seen, while on the upper right of the tracing a branch of the pulmonary vein is cut somewhat obliquely Sections of smaller veins are shown in clear outline in the connective tissue surrounding the lobule Following the course of the bronchiole throughout the lobule, its mode of division can be made out A large branch is cut off obliquely near the center of the section and another branch is indicated by the shoulder which projects on the right of the bronchiole a short distance from its entrance into the lobule In the final division of the bronchiole situated in that portion of the section between the pulmonary vein and bronchus, the walls of the bronchioli respiratorii and the ductulus alveolaris are indicated in heavier outline than the walls of the surrounding alveoli Some might consider all that portion of the section situated between the pulmonary vein and the bronchus as an acinus, but it can be readily seen that this does not represent the classic description of

an acinus; neither does it represent a primary lobule. Within the lobule branches of the pulmonary artery are indicated in solid black.

By studying the tracing, one can easily understand the misconception of lung structure which the older authors received

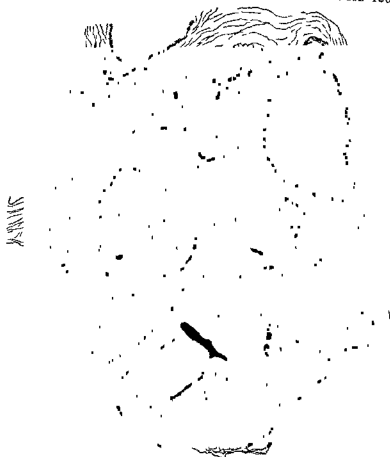


Fig. 167.—Camera lucida tracing of a secondary lobule situated 55 mm below the pleura of the human lung The tracing is composed of two sections, each 40μ thick. This was done in order that the bronchiole could be shown throughout its whole length. For description see text ×4 5

from the study of single sections that included as many air spaces as -

' is taken (I am

acc by 70 mm.), I

found an "acinus" (Fig. 168) which corresponds to Braus' reproduction of Loeschcke's corrosion of an acinus.

While the acinus photographed is not like that of Loeschcke Berdal and others situated directly beneath the pleura that it is from the distal portion of a bronchial ramification is shown by the longitudinal section of the vein seen in the lower portion of the figure

In many ways it corresponds to Loeschcke s corrosion for on the right division of his *bronchiolus minimus* there is a furrow for

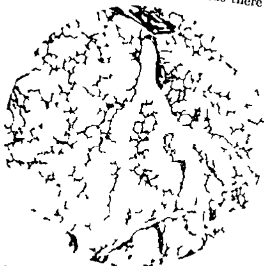


Fig 168 —Section through what corresponds to the acinus illustrated in Figure 165 This is taken from the same section as Figure 167 ×7 5

a branch of the arteria pulmonalis and in practically the same situation in the photograph a branch of the artery has been cut somewhat obliquely His bronchiolus divides into two branches the same is true of the bronchiolus in Figure 168 these two branches are *bronchioli respiratorii* The bronch[illegible] on the right of the photograph [illegible] while on the left a [illegible] atrium and sacculus [illegible] passing to air space [illegible] not shown [illegible] branches [illegible] the level of the section are not shown Reconstructions of the series and its dissection alone would bring out their proper relationship Figure 168 corresponds but not so closely to Berdal s figure In each instance one sees that the acinus is *not* the final division of the bronchial tree and that it is the primary lobule with its blood vessels lymphatics and nerves that forms the unit of construction

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(Authors and Subjects)

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